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Investigation on the Effectiveness of Variable Frequency Drive Application in Solar-Powered Water Pumps: A Systematic Review

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Abstract— The integration of Variable Frequency Drives (VFDs) into solar-powered water pumps (SWPs) offers a potential leap towards eco-friendliness and cost-efficiency, particularly in the agricultural sector. Despite the known benefits of VFDs in enhancing traditional pump efficiency, their impact on SWPs remains underexplored. This systematic review meticulously investigates the role of VFDs within SWPs, focusing on their reliability, performance enhancements, and economic impact. Utilizing the PRISMA method, the review distilled insights from 898 records, ultimately scrutinizing 29 studies that discuss the effectiveness and overall evaluation of VFDs in SWPs, with a subset of 8 studies endorsing their high efficacy. The findings aim to consolidate current knowledge, support stakeholder decisions, and carve a path for subsequent research endeavors. This evaluation sheds light on the tangible advantages of VFDs in solar-powered setups, marking a significant step in sustainable energy application and reducing carbon footprints in agricultural practices. The evidence underscores the transformative potential of VFDs in SWPs and calls for increased attention to this synergy to harness the full spectrum of environmental and economic benefits.

Keywords— Irrigation, Solar-Powered Water Pumps (SWPs), Systematic Review, Sustainable Energy, Variable Frequency Drives (VFD)

I. INTRODUCTION

Water pumps are essential across multiple domains such as agriculture, domestic settings, and industrial activities. Their use in agriculture is especially crucial, enhancing the irrigation of expansive fields, thereby markedly improving crop yield and quality (Ahmed et al., 2023). In the context of an increasing focus on sustainable energy practices, solar energy stands out as a green substitute for conventional power sources. Solar-powered water pumps are gaining prominence due to their potential to cut down on greenhouse gas emissions and lower running expenses (Zaky et al., 2022).

Despite the potential of solar-powered water pumps, typical water pumps that run on fossil fuels or grid energy have several drawbacks, including high running costs and environmental concerns. Variable Frequency Drives (VFD) are one technology used to improve the efficiency of these pumps. The usefulness of implementing VFDs in solar-powered water pumps, on the other hand, has not been properly examined (Alnassan et al., 2021). The primary goal of this systematic review is to thoroughly evaluate existing literature and studies on the effectiveness of Variable Frequency Drive applications in solar-powered water pumps.

Considering the rising interest in sustainable energy solutions and the critical role of water pumps in various sectors, it is timely and crucial to evaluate the efficacy of VFDs in solar-powered systems. A systematic review in this area will provide a structured and comprehensive synthesis of existing knowledge, thus helping stakeholders make informed decisions and guiding future research endeavors (Alnassan et al., 2021). By exploring the effectiveness of Variable Frequency Drives in enhancing the efficiency of solar-powered water pumps, this review aims to fill the current gap in literature and contribute to both academic and practical advancements in the field.

II. METHODOLOGY

Through a systematic examination, the paper examines the effectiveness of VFD applications in solar-powered water pumps. This research is important because renewable energy options, particularly solar power, are becoming more important in tackling global energy concerns. A PRISMA-based systematic review of the literature will be conducted. This will ensure high-quality studies and reliable data for conclusive evidence.

A. Identification

The first phase in the PRISMA methodology is the identification of relevant studies and literature. We will be searching scientific databases such as ProQuest, Google Scholar, and ScienceDirect for articles, conference papers, and reports that focus on VFD applications in solar-powered water pumps. Search terms will include combinations of "Variable Frequency Drive," "VFD," "Solar-Powered," "Water Pumps," "Efficiency," and "Effectiveness." Initial identification will focus on casting a wide net, aiming to include as many potentially relevant articles as possible.

B. Screening

Following the identification phase, a screening process will be executed to filter out irrelevant or low-quality studies. Criteria for screening will include the relevance of the study to the topic, the scientific rigor of the methodology, and the quality of data reported. Any study not meeting these basic criteria will be excluded from further consideration. This phase aims to refine the collection of articles to those that specifically contribute to the understanding of the effectiveness of VFDs in solar-powered water pumps.

C. Eligibility

In the eligibility phase, the remaining articles will be examined in greater depth. This involves scrutinizing the methodology, data analysis techniques, and conclusions of each paper. Studies will be considered eligible if they provide quantifiable measures of the effectiveness of VFD applications in solar-powered water pumps, if they are peer-reviewed, and if they contribute novel insights or data. Any articles that do not meet these specific criteria will be excluded.

D. Inclusion

The final phase is the inclusion of the selected studies into the systematic review. These studies will undergo a thorough analysis, with key data and findings being extracted and compiled. Comparisons will be made on various metrics such as efficiency, cost-effectiveness, and sustainability of VFD applications in solar-powered water pumps. Then the available evidence is synthesized to present a clear picture of the current state of knowledge on the subject.

E. Data Synthesis and Analysis

The data extracted from the selected studies will be organized and assessed with a focus on evaluating the effectiveness of Variable Frequency Drives (VFDs) in solar-powered water pumps (SWPs). The evaluation framework will categorize the data into three key areas: 'VFD Effectiveness,' where studies that directly measure the performance improvements attributed to VFDs will be analyzed; 'Alternative Methods Evaluated,' which will encompass studies that assess other methodologies besides VFDs for enhancing SWP efficiency; and 'General Performance Evaluation,' where research that provides a broader analysis of SWP performance metrics will be considered. This categorical approach will facilitate a structured analysis, enabling a comprehensive understanding of VFD impacts in SWPs, the relative performance of alternative methods, and the general operational efficacy of these systems.

III. RESULTS AND DISCUSSION

A. PRISMA Statement

The systematic review on the effectiveness of VFDs in solar-powered water pumps followed a stringent PRISMA protocol. An initial search across databases such as ScienceDirect, ProQuest, and Google Scholar yielded 898 records, which were reduced to 571 after the removal of 327 duplicates. Subsequent screening based on titles and abstracts further narrowed the field, excluding 536 records for reasons such as irrelevance or insufficient scientific rigor, leaving 35 for full-text review. All 35 were accessible and underwent a detailed eligibility assessment, resulting in the exclusion of six due to factors like age and lack of peer review, culminating in 29 studies deemed suitable for inclusion.

This thorough selection process ensured the inclusion of the most pertinent and scientifically valid studies. From an extensive initial literature collection, the process extracted a core group of 29 studies poised to offer comprehensive insights into the role of VFDs in enhancing the performance of solar-powered water pumps. The deliberate exclusion of outdated and non-peer-reviewed material reinforces the trustworthiness of the research findings, providing a clear and current understanding of VFD applications in this green technology segment.

Fig. 1 illustrates a fluctuating scholarly engagement with the use of VFDs in SWPs across different years. An increase in research activity in recent times suggests an escalating interest and perhaps advancements in the technology. The scarcity of studies in earlier periods could reflect historical constraints or a lower prioritization of the topic. Annual fluctuations in the volume of research may also reflect the impact of external elements such as shifts in funding availability or regulatory frameworks.

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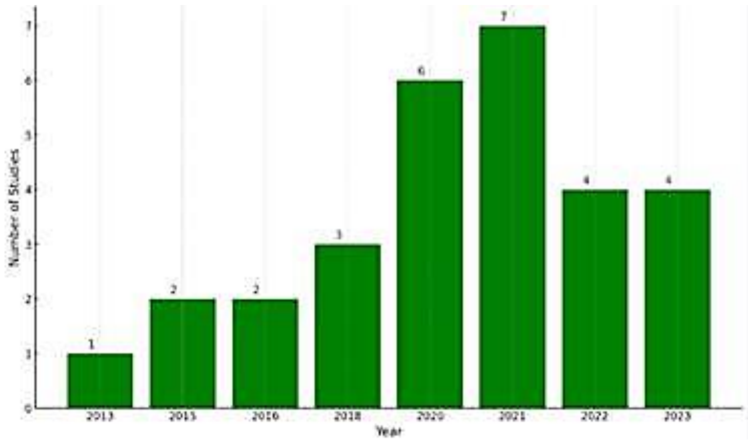

Figure 1. *Studies related to VFDs and SWPs from 2013 to 2023*

B. Effectiveness of VFD in SWPs

Based on the categorization, the distribution of studies on the effectiveness of VDFs in SPWs presents an intriguing landscape. Out of the 29 studies analyzed, only two were categorized as "Highly Effective," while the overwhelming majority, 27 studies, fell into the "Less Effective or Inconclusive" category. Interestingly, there were no studies that met the criteria for being "Moderately Effective," shedding light on the polarized nature of existing research.

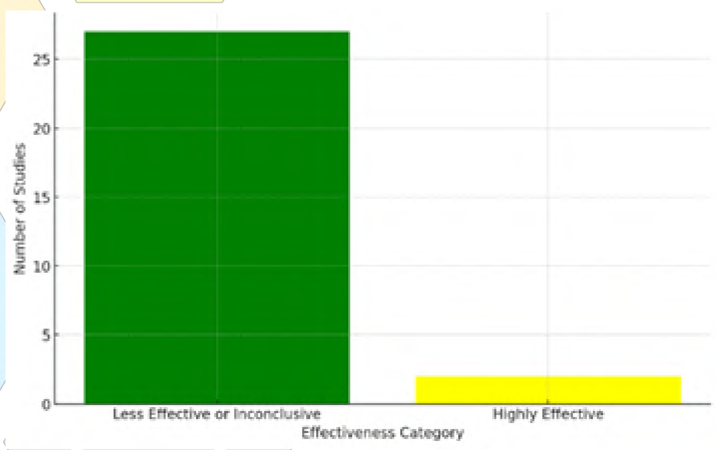

Figure 2. *Distribution of Studies Based on the*

Effectiveness of VFDs in SWP

This distribution is shown in Fig. 2, where most of the studies skewed toward inconclusive or less effective results. Such a lopsided distribution suggests a pressing need for more comprehensive research in this domain. Future studies should aim to address the research gaps and ambiguities that were evident in the existing body of work, with a particular focus on establishing the effectiveness of VFDs in SPWs in a more unequivocal manner.

The two studies identified as "Highly Effective" in demonstrating the utility of VFDs in SPWs offer compelling insights. The first study, conducted in 2022 by Zaky et al., focuses on employing Dye-Sensitized Solar Cells (DSSCs) in tandem with VFDs. This research highlights the high efficiency and cost-effectiveness of the system, although it notes a research gap in the limited existing studies that combine DSSCs with VFDs. The second study, authored in 2021 by Hmidet et al., presents an efficient off-grid solar photovoltaic water pumping system incorporating VFDs. The study underscores its promising utility, particularly for remote areas without electricity access, while also indicating a lack of comparative analysis with other systems in the existing literature. Both studies serve as valuable benchmarks, emphasizing the high efficiency and substantial improvements possible when integrating VFDs into SPW systems.

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C. Evaluation of VFD in SWPs

In the re-categorization of studies based on their objectives, the academic landscape on the effectiveness and performance of VFDs in SPWs emerges as both diverse and specialized. The studies were grouped into three distinct categories: those focusing on confirming the effectiveness of VFDs, those exploring alternative methods for performance evaluation, and those conducting a general performance evaluation of SPWs. These categorizations were made by examining the Title, Key Findings, and Significance of the Study columns in each paper. Fig. 3 represents the distribution of 8 studies confirming VFD effectiveness, 3 studies evaluating alternative methods, and 18 studies engaged in general performance evaluation.

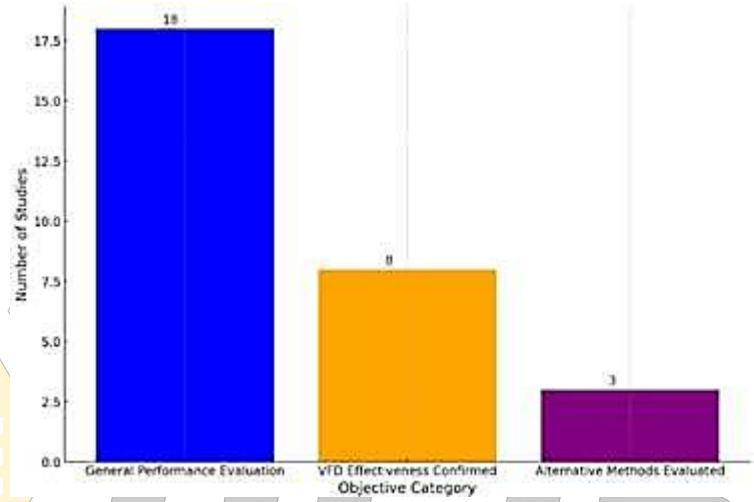

Figure 3. *Evaluation of VFDs in SWP*

Objectives of the Study

Notably, there was a marked academic interest in affirming the effectiveness of VFDs, as evidenced by 8 out of 29 studies specifically investigating this aspect. However, only 3 studies ventured into exploring alternative methods, indicating this as a potential avenue for future research. The bulk of the studies, totaling 18, were more generalized in their approach, evaluating the overall performance of SPWs without exclusively focusing on VFDs. This highlights a broad yet targeted academic focus on various facets of solar water pump performance.

VFD Effectiveness. Table 1 contains 8 studies that specifically focus on confirming the effectiveness of VFDs in SPWs. These studies range from the year 2015 to 2021 and cover various aspects like design interfacing circuits, economic considerations, and efficiency enhancements.

These studies, making up about 28% of the total, delve into various aspects such as design considerations (Eltawil et al., 2021), energy savings (Mancosky, 2018), and efficiency enhancements (Shaik et al., 2020). The focus here is largely empirical, aiming to quantify the performance gains, efficiency improvements, or cost savings that can be achieved through the integration of VFDs. This focused inquiry reflects not just academic curiosity but possibly an industry-driven need to optimize SWPs using VFDs.

Table 1. *Summary of Studies Confirming VFD Effectiveness*

Author	Year	Title
Alnassan et al.	2021	Analysis And Design Interfacing Circuit to Implement Industrial VFD In Photovoltaic Water Pumping
Elmahni et al.	2021	Technico-Economic Study of a Photovoltaic Pumping System Using a Variable-Frequency Drive Converter
Eltawil et al.	2021	Design Of a Solar PV Powered Variable Frequency Drive for a Bubbler Irrigation System in Palm Trees Fields
Mendonça et al.	2021	Performance Of Oversized Pumps Controlled by Variable Frequency Drives in Water Supply Systems

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Mancosky, Connor J.	2018	Evaluation Of Energy Savings Potential from Deep Well Variable Frequency Drive Installation
Raghuwanshi et al.	2018	Sizing and implementation of Photovoltaic Water Pumping System for Irrigation
Shaik et al.	2020	Efficiency enhancement in a PV operated solar pump by effective design of VFD and tracking system
Yadav et al.	2015	Performance comparison of controllers for solar PV water pumping applications

Alternative Methods Evaluated. Table 2 shows 3 studies that explore alternative methods for evaluating or improving the performance of SPWs. These studies were conducted between 2015 and 2020.

Table 2. *Summary of Studies Evaluating Alternative Methods in Improving SPWs*

Author	**Year**	**Title**
Kumar et al.	2020	Mitigated Solar Water Pump System Deployed on Frequency Control of the Induction Engine
Jones et al.	2016	Economic analysis of photovoltaic (PV) powered water pumping and desalination without energy storage for agriculture
Khan et al.	2015	Design and Simulation of 0.75hp Soft Start AC Water Pump Powered by PV Solar System

Although limited in number and constituting about 10% of the total studies, these papers provide valuable comparative insights. For instance, Gaurav Kumar and Kabra (2020) explore a cloud-deployed system, while Khan et al. (2015) delves into soft start AC motors. These studies broaden the academic landscape by offering alternative avenues for performance gains and potentially setting the stage for multi-technology comparative studies. They add breadth to the subject by introducing and evaluating other technological solutions, such as cloud deployment or soft start AC motors. These studies may not necessarily dispute the effectiveness of VFDs but offer other avenues for achieving performance gains, thereby broadening the scope for innovation.

General Performance Evaluation. This category is the most extensive, containing 18 studies that don't necessarily focus on VFDs but aim to evaluate the overall performance of SPWs. The studies in this table cover a range of years, from 2013 to 2023, and encompass a wide array of topics like reliability assessments, energy generation predictions, and metaheuristic algorithms. Though they may not directly confirm the effectiveness of VFDs, they contribute to a broader understanding of performance parameters in SPW systems.

Table 3. *Summary of Studies Evaluating General Performance of SPWs*

Author	**Year**	**Title**
Ahmed et al.	2023	Reliability And Performance Evaluation of a Solar PV-Powered Underground Water Pumping System
Zaky et al.	2022	Employing Dye-Sensitized Solar Arrays and Synchronous Reluctance Motors to Improve the Total Cost and Energy Efficiency of Solar Water-Pumping Systems
Ammar et al.	2023	Evaluation Of the Performance of A FONN-Based MPPT Control for A Photovoltaic Watering System
Chinthamalla et al.	2016	A Discontinuous Switching Technique to Eliminate Common Mode Voltage with Reduced Switching Losses for An Open-End Winding Induction Motor Drive Solar Water Pump
Hadole et al.	2022	Modeling And Planning Operation of Directly Coupled Solar Photovoltaic Pump Operated Drip Irrigation System with A Case Study
Hadole et al.	2021	Energy Generation and Flow Rate Prediction of Photovoltaic Water Pumping System for Irrigation
Hina et al.	2020	Impacts Of Barrier Shape on Torque Ripple and Saliency in Synchronous Reluctance Motor for Solar Water Pumping

Hmidet et al.	2021	Design Of Efficient Off-Grid Solar Photovoltaic Water Pumping System Based on Improved Fractional Open Circuit Voltage MPPT Technique
Kumari, and Dahiya	2018	Speed Control of Solar Water Pumping with Indirect Vector Control Technique
Miran et al.	2022	Optimization Of Standalone Photovoltaic Drip Irrigation System: A Simulation Study
Narendra et al.	2023	Solar PV Fed FSVSI Based Variable Speed IM Drive Using ASVM Technique
Nisha and Gnana	2022	Metaheuristic Algorithm Based Maximum Power Point Tracking Technique Combined with One Cycle Control for Solar Photovoltaic Water Pumping Systems
S. G. Malla et al.	2023	Modified Invasive Weed Optimization for The Control of Photovoltaic Powered Induction Motor Drives in Water Pumping Systems
Sadasivam et al.	2013	Analysis Of Subsystems Behaviour and Performance Evaluation of Solar Photovoltaic Powered Water Pumping System
Senthil Kumar et al.	2020	Solar Powered Water Pumping Systems for Irrigation: A Comprehensive Review on Developments and Prospects Towards a Green Energy Approach
Poompavai and Kawsayla	2020	Investigation Of Standalone Solar Photovoltaic Water Pumping System with Reduced Switch Multilevel Inverter
Vamja et al.	2020	Multipurpose Battery-Assisted Solar Water Pumping System for Off-Grid Applications: Design and Development
Vanaja et al	2021	Investigation And Validation of Solar Photovoltaic-Fed Modular Multilevel Inverter for Marine Water-Pumping Applications

The most extensive category, containing 18 studies, adopts a broader lens for examining SWP performance. About 62% of the total studies fall under this umbrella, covering a gamut of topics from reliability assessments (Ahmed et al., 2023) to energy generation predictions (Alaa A. Zaky et al., 2022). While these studies may not concentrate on VFDs, they contribute to an overarching understanding of SWP performance parameters. Their generalized approach provides a backdrop against which the utility of specialized technologies like VFDs can be more comprehensively evaluated.

IV. CONCLUSION

This paper presents a thorough review that carefully followed the PRISMA guidelines to look at how well Variable Frequency Drives (VFDs) work in solar-powered water pumps (SWPs). When we started our research, there were 898 studies to choose from. We carefully picked out 29 of the most important and scientifically sound studies. The findings show that people have very different opinions about how well VFDs work, with most studies saying they are less effective or not clear. This disagreement makes it clear that more study is needed to find out for sure what the benefits of using VFDs in SWPs are. The study of research activities over time also showed that there was rising interest in this area, both in academia and possibly in technology. This shows that the field is changing, and the research frontiers are growing.

Because of these observations, it is suggested that more detailed study be done in the future. There is a clear need for actual studies that not only look at how well VFDs work but also compare them to other technologies that make SWPs more efficient. There is also a chance to include studies on alternative methods and full performance reviews, which are not currently included in the main body of research. This broader view could shed light on different performance aspects of SWPs, helping us gain a deeper knowledge of how they work. Lastly, there needs to be more cooperation between academia and the business world in order to turn these academic discoveries into useful technologies that can be used in real life to make farming more environmentally friendly. Adopting these suggestions will not only help the field move forward scientifically, but it will also help the farming industry move toward more environmentally friendly and energy-saving methods.

REFERENCES

[1] Ahmed, N. M., Hassan, A. M., Kassem, M. A., Hegazi, A. M., & Elsaadawi, Y. F., “Reliability and performance evaluation of a solar PV-powered underground water pumping system,” Scientific Reports Nature Group, vol. 13(1), 2023. https://doi.org/10.1038/s41598-023-41272-5.

[2] Alaa A. Zaky, Sergeant, P., Stathatos, E., Falaras, P., & Ibrahim, M. N. F., “Employing Dye-Sensitized Solar Arrays and Synchronous

Reluctance Motors to Improve the Total Cost and Energy Efficiency of Solar Water-Pumping Systems," Machines, vol. 10(10), pp. 882, 2021. https://doi.org/10.3390/machines10100882
[3] Alnassan, G., Sharam, A., & Habra, W., "Analysis and Design Interfacing Circuit to Implement Industrial VFD in Photovoltaic Water Pumping," International Journal of Computer Applications, vol. 174(20), pp. 30-37, 2021. https://doi.org/10.5120/ijca2021921101
[4] Ammar, H. H., Azar, A. T., Mahmoud, M. I., & Shalaby, R., "Evaluation of the performance of a FONN-based MPPT control for a photovoltaic watering system," Ain Shams Engineering Journal, 2023. https://doi.org/10.1016/j.asej.2023.102329
[5] Chinthamalla, R., Sahoo, D., Jain, S. H., & Sachin Jain., "A Discontinuous switching technique to eliminate Common Mode Voltage with reduced switching losses for an Open End Winding Induction Motor drive solar water pump," European Conference on Electrical Engineering and Computer Science, pp. 1-5, 2016. https://doi.org/10.1109/sceecs.2016.7509304
[6] Elmahni, L., Assalaou, K., Aitiaz, E., Benachir, B., & Bouhouch, L., "Technico-Economic Study of a Photovoltaic Pumping System Using a Variable-Frequency Drive Converter," E3S Web of Conferences, vol. 229, 2021. https://doi.org/10.1051/e3sconf/202122901017
[7] Eltawil, M. A., Alhashem, H. A., & Alghannam, A. O., "Design of a solar PV powered variable frequency drive for a bubbler irrigation system in palm trees fields," Process Safety and Environmental Protection, vol. 152, pp. 140-153, 2021. https://doi.org/10.1016/j.psep.2021.05.038
[8] Gaurav Kumar & S.S. Kabra., "Mitigated Solar Water Pump System Deployed on Frequency Control of the Induction Engine," Advanced Science, Engineering and Medicine, vol. 12(11), pp. 1403-1407, 2020. https://doi.org/10.1166/asem.2020.2594
[9] Hadole, M. V., Prabodh Bajpai, & Kamlesh Narayan Tiwari., "Modeling and planning operation of directly coupled solar photovoltaic pump operated drip irrigation system with a case study," Clean Technologies and Environmental Policy, 2022. https://doi.org/10.1007/s10098-022-02376-0
[10] Hadole, M. V., Tiwari, K. N., & Bajpai Prabodh., "Energy generation and flow rate prediction of photovoltaic water pumping system for irrigation," Environment, Development and Sustainability, vol. 23(5), pp. 6722-6733, 2021. https://doi.org/10.1007/s10668-020-00886-9
[11] Hina Parveen, Sharma, U., & Singh, B., "Impacts of barrier shape on torque ripple and saliency in synchronous reluctance motor for solar water pumping," IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy, 2020. https://doi.org/10.1109/pesgre45664.2020.9070740
[12] Hmidet, A., Subramaniam, U., Elavarasan, R. M., Raju, K., Diaz, M., Das, N., Mehmood, K., Karthick, A., M. Muhibbullah, & Boubaker, O., "Design of Efficient Off-Grid Solar Photovoltaic Water Pumping System Based on Improved Fractional Open Circuit Voltage MPPT Technique," International Journal of Photoenergy, pp. 1–18, 2021. https://doi.org/10.1155/2021/4925433
[13] Jones, M. A., Odeh, I., Haddad, M., Mohammad, A. H., & Quinn, J. C., "Economic analysis of photovoltaic (PV) powered water pumping and desalination without energy storage for agriculture," Desalination, vol. 387, pp. 35-45, 2016. https://doi.org/10.1016/j.desal.2016.02.035
[14] Gomes, K. H. M. H., Villanueva, J. M. M., & Bezerra, S. D. T. M., "Performance of Oversized Pumps Controlled by Variable Frequency Drives in Water Supply Systems," Journal of Urban and Environmental Engineering, 2021. https://doi.org/10.4090/juee.2022.v16n2.186-192
[15] Khan, R. A., Khan, L. A., & Hussain, S. Z., "Design and Simulation of 0.75hp Start AC Water Pump Powered by PV Solar System," Universal Journal of Mechanical Engineering, vol. 3(4), pp. 113-121, 2015. https://doi.org/10.13189/ujme.2015.030401
[16] Kumari, R., & Dahiya, R., "Speed control of solar water pumping with indirect vector control technique," International Conference on Information Security and Cryptology, 2018. https://doi.org/10.1109/icisc.2018.8399039
[17] Mancosky, C. J., "Evaluation of Energy Savings Potential from Deep Well Variable Frequency Drive Installation"
[18] Miran, S., Tamoor, M., Tayybah Kiren, Raza, F., Muhammad Imtiaz Hussain, & Jun-Tae, K., "Optimization of Standalone Photovoltaic Drip Irrigation System: A Simulation Study," ProQuest

Central, vol. 14(14), pp. 8515, 2022. https://doi.org/10.3390/su14148515

[19] Narendra, A., Naik N, V., Panda, A. K., & Lenka, R. K., "Solar PV fed FSVSI based Variable Speed IM Drive using ASVM Technique," Engineering Science and Technology, an International Journal, vol. 40, pp. 101366, 2023. https://doi.org/10.1016/j.jestch.2023.101366

[20] Nisha R & Gnana Sheela K., "Metaheuristic Algorithm Based Maximum Power Point Tracking Technique Combined With One Cycle Control For Solar Photovoltaic Water Pumping Systems," Frontiers in Energy Research, vol. 10, 2022. https://doi.org/10.3389/fenrg.2022.902443

[21] Paredes, M., Ruiz, D., Jara, W., Pena, R., & Riedemann, J., "Model Predictive Control of a Quasi-Three-Level Inverter Topology Supplying Multiple Solar-Powered Pumps," International Symposium on Power Electronics for Distributed Generation Systems, 2020. https://doi.org/10.1109/pedg48541.2020.9244355

[22] Raghuwanshi, S. S., & Khare, V., "Sizing and implementation of Photovoltaic Water Pumping System for Irrigation," IAES International Journal of Artificial Intelligence, vol. 7(1), pp. 54-62.

[23] Rawat, R., Kaushik, S. C., & Lamba, R., "A review on modeling, design methodology and size optimization of photovoltaic based water pumping, standalone and grid connected system," Renewable & Sustainable Energy Reviews, vol. 57, pp. 1506-1519, 2016. https://doi.org/10.1016/j.rser.2015.12.228

[24] Renu, B., Prasad, B., Sastry, O. S., Kumar, A., & Bangar, M., "Optimum sizing and performance modeling of Solar Photovoltaic (SPV) water pumps for different climatic conditions," Solar Energy, vol. 155, pp. 1326-13338, 2017. https://doi.org/10.1016/j.solener.2017.07.058

[25] Malla, S. G., Priyanka Malla, M. Karthik, D. Kumar, & Awad, H., "Modified Invasive Weed Optimization for the Control of Photovoltaic Powered Induction Motor Drives in Water Pumping Systems," Iranian Journal of Science and Technology Transactions of Electrical Engineering, 2023. https://doi.org/10.1007/s40998-023-00589-7

[26] Sadasivam, P., Kumaravel, M., Vasudevan, K., & Jhunjhunwala, A., "Analysis of subsystems behaviour and performance evaluation of solar photovoltaic powered water pumping system," 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC), pp. 2932-2937, 2013. https://doi.org/10.1109/PVSC.2013.6745080

[27] Senthil Kumar, S., Bibin, C., Akash, K., Aravindan, K., Kishore, M., & Magesh, G., "Solar powered water pumping systems for irrigation: A comprehensive review on developments and prospects towards a green energy approach," Materials Today: Proceedings, vol. 33, pp. 303-307, 2020. https://doi.org/10.1016/j.matpr.2020.04.092

[28] Shaik, R., Beemkumar, N., Adharsha, H., Venkadeshwaran, K., & Dhass, A. D., "Efficiency enhancement in a PV operated solar pump by effective design of VFD and tracking system," International Conference on Future Generation Functional Materials and Research, vol. 33, pp. 454-462, 2020. https://doi.org/10.1016/j.matpr.2020.05.035

[29] Shinde, V. B., & Wandre, S. S., "Solar photovoltaic water pumping system for irrigation: A review," African Journal of Agricultural Research, vol. 10(22), pp. 2267-2273, 2015. https://doi.org/10.5897/ajar2015.9879

[30] Poompavai, T. & Kowsalya, M., "Investigation of Standalone Solar Photovoltaic Water Pumping System With Reduced Switch Multilevel Inverter," Frontiers in Energy Research, vol. 8, 2020. https://doi.org/10.3389/fenrg.2020.00009

[31] Vamja, R. V., & Mulla, M. A., "Multipurpose battery-assisted solar water pumping system for off-grid applications: Design and development," Iet Electric Power Applications, vol. 14(14), pp. 2717-2730, 2020. https://doi.org/10.1049/iet-epa.2020.0511

[32] Vanaja, D. S., Stonier, A. A., Mani, G., & Murugesan, S., "Investigation and validation of solar photovoltaic-fed modular multilevel inverter for marine water-pumping applications," Electrical Engineering, pp. 1-16, 2021. https://doi.org/10.1007/s00202-021-01370-x

[33] Yadav, K., Sastry, O. S., Wandhare, R., Sheth, N., Kumar, M., Bora, B., Singh, R., Renu, & Kumar, A., "Performance comparison of controllers for solar PV water pumping applications," Solar Energy, vol. 119, pp. 195-202, 2015. https://doi.org/10.1016/j.solener.2015.06.050