Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Adapted Irrigation Pump Load in Solar PV and Wind Energy Systems through Stepped Variable Frequency Drives

Samson Sing'oei SOSHYO
Technical University of Mombasa, Mombasa, Kenya, samsonsoshyo@gmail.com

Sameer Kamrudin **BACHANI**
Technical University of Mombasa, Mombasa, Kenya

Michael Juma **SAULO**
Technical University of Mombasa, Mombasa, Kenya

Lawrence Manyonge **MUKHONGO**
Technical University of Mombasa, Mombasa, Kenya

Received: 11 December 2023

Review: 18 December 2023

Accepted: 21 December 2023

Published: 30 December 2023

Abstract—Wind and solar photovoltaic (solar-PV) power are highly variable and intermittent as exhibited by corresponding generation profiles. In the utilization of power directly for water pumping, the availability and reliability of water automatically followed the Renewable Energy Sources (RES) characteristics. On the other hand, Deferrable Irrigation Load (DIL), followed a specific irrigation water need profile. The DIL profile is determined by crop cycles and corresponding water needs. It was also affected by aspects of weather, mainly precipitation, temperature, and wind. This research considered the application of discrete switches and Variable Frequency Drives (VFDs) as a combined solution. Combined discrete and continuous switching through VFDs, to adapt pump load to DIL and RES profiles proved successful. Discrete switches engaged the exact number of pumps required to match an expected irrigation load. VFD further ensured continuous match of irrigation pump load to the anticipated DIL curve, through adjustment of pump speed points. Running of the system to adapt the pump power to the RES curve yielded better curve-fit results. The energy adapting technique was implemented to improve elasticity, hence the efficiency of the system. The results showed that the adapted system to the DIL curve-fit was 95.4% compared with a discrete-only system (91.35%). This represented a slight improvement of approximately 4.5%. The results demonstrated the smoother operation of the pump system and increased energy utilization efficiency. A further improvement on the control strategy for VFD coupled with the re-design of irrigation pipe networks was required to improve efficiency beyond 95.4%.

Keywords—*Renewable Energy, Wind, Solar PV, Irrigation Pump, Variable Frequency Drive*

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

1 Introduction

Kenya faces a food shortage problem, just like many other countries in the developing world. In all these countries, there is a need to address the food security problem (National Irrigation Board, 2018). Kenya has put in place strategies to shift focus from rain-fed agriculture to irrigation agriculture. Kenya has earmarked several irrigation projects and corresponding sites some of which are: Galana-Kulalu, Lotikipi, Perkerra, Rahole, and Wei Wei for this purpose [1]. The project's main purpose is to address the food security problem although significant commercial interest still exists, especially if cash crops can be grown there. However, there is a huge problem in the projects caused by the high pump costs, which increases the cost of food production, consequently leading to the lackluster performance of the projects. In the global struggle to ensure that, the Sustainable Development Goals (SDGs) [2] overarches national development, affordable and clean energy as well as zero hunger are key. In this pursuit, Kenya invested heavily in the financing of irrigation agriculture. For instance, in 2018, the Galana-Kulalu Food Project secured a loan whereby Bank Leumi of Israel signed KES 6.35 billion to finance the contract. Kenya also spent a significant amount of funding on other irrigation projects (Lotikipi, Perkerra, Rahole, and Wei Wei). The major cost of production in all these projects is the diesel used in the pumps or electric generators. Where there is a grid connection, the high electricity bills are also a discouragement [2]. However, in most irrigation sites there are significant renewable energy sources mainly solar PV [3] and wind. This presents the opportunity to tap these resources to address the high pump costs, thereby increasing irrigation energy efficiency thus reducing the cost of food produced. Other benefits include the reduction of environmental pollution through minimizing of carbon emissions, smoke, or noise mainly attributed to diesel pump engines or electric generators [4].

1.1 Problem Statement

One of the major challenges of irrigation projects was high input costs, due to diesel used by the diesel pumps and electric generators. However, there existed a solution in renewable energy source harnessing, particularly on hybrid wind and solar-PV energy. These alternative sources were variable and intermittent, and so were irrigation water needs and corresponding energy needs. It was, therefore, worth developing systems, which adapted pumps to (1) resultant Deferrable Irrigation Load (DIL), or to (2) Renewable Energy Resources (RES) themselves. A system combining discrete and continuous pump operation using Variable Frequency Drives (VFDs) was required as a possible pump adapting solution for effective and efficient utilization of energy in irrigation systems. It was necessary to run the adapted models on predetermined economic optimized energy system structures. Accurate modelling of the operation of energy systems to determine effectiveness and efficiency of such a system in terms of surpluses or deficits of energy generated vis-a-vis energy utilized.

1.2 Objectives of Study

Main Objective was to simulate and analyze irrigation energy utilization for adapted irrigation pump load, in economic optimized hybrid wind-solar energy system, using stepped variable frequency technique.

Specific Objectives were: (1) To simulate pumps adapted to deferrable irrigation load using stepped variable frequency technique; (2) To simulate pumps adapted to renewable energy resource using stepped variable frequency technique; and (3) to analyze percentage of curve fitting in crop-specific and site-specific scenarios in the applied stepped variable frequency technique.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

2 Literature Review

There were several solutions proposed to solve modern-day Energy-Water-Food (EWF) nexus-type problems [4]. This is whereby by solving energy problems in water provision, the food problems reduced significantly [5]. The Kenya government hired Green Arava an Israeli company to offer development and management services to a 10,000-acre test firm at Galana-Kulalu [6]. The crop under irrigation was maize. The agricultural officers [6] pursued the possibility of including other crops namely: beans, sugarcane, cotton, vegetables, or fruits. The pumps engaged could be as high as 15 units could or as low as one during a typical harvesting season. The price of diesel is usually high for example in Kenya at present is approximately $2, especially in the far-flung areas where the irrigation sites are located. Where direct diesel pumps are used, there is still a big issue concerning repairs and maintenance of the units [6]. The situation is a little better when diesel electric generators are used to power electric pumps [7]. Electric pumps whether submersible or surface-mounted are induction machines by nature.

2.1 Variable Frequency Drives

Variable Frequency Drives (VFDs) dominated electrical machine utilization for decades. There was significant use of power electronics to modulate frequency supply to vary the speed of the induction machine. There was utilization of VFDs in irrigation systems for driving the Induction Motor Pump [8]. In smart irrigation systems [9] electric drives vary in frequency consequently the water discharge required in farms. [10]developed variable-speed water pumping for photovoltaic systems. The system was for low-scale irrigation. [11] Still worked on photovoltaic systems for small farms. Optimal control of water used in irrigation farms was done by [11] using variable speed drives. There was efficiency and cost savings of the system as compared with the ON/OFF systems (discrete systems). There was deployment of Artificial intelligence (AI) technique to run a variable speed water pumping system by [11]. The Ant System Iteration Best (ASib) proved to yield 10% economic pump savings. The ASib was better than the Genetic Algorithm (GA) in this problem [12]. A problem of pumping systems design and performance was studied by [13]who compared reservoir and pump conditions and established that elevation and pump distances had a significant impact on efficiency. Center pivot irrigation systems were studied by [14] who found that a reduction of energy consumption by 12.2% was possible with the use of variable speed drives. The economic advantages of VFDs were studied by [15] who discovered that the use of VFDs reduced the investment costs by 15%. Detailed Study of pump affinity laws in [10] showed the relationship between rotor speed and discharge as well as power. This was a research on the MATLAB/Simulink platform. Renewable Energy in Irrigation

The use of renewable energy in irrigation was studied by [16] who studied hybrid wind-solar systems on small-scale farms (<2.0 Ha) and added farm uses where excess winds were experienced. [17] Also developed a hybrid wind-solar system for a dragon fruit field measuring 3000m^2 thus reducing the dependence on fossil fuels. [17] Studied the beneficial economics of a small-scale banana farm in Uganda. [18] Automated modern farming system and found out that it was favorably economical. Wind pump conditions were competently studied by [19], [20], [21], and [22] and all were in agreement that wind pumping for irrigation agriculture were more suited that solar PV systems. It was possible to bring large areas under irrigation with wind-powered pump systems.

2.1 Research Gap

There was an emerging gap in irrigation load modeling and characterization with VFD technology applied. In all the literature studied, rarely did the researchers develop annual models considering the nature of irrigation. They had dwelt less on irrigation load characterization and profiling. Further, still there was less emphasis given to the potential harnessing of RES at corresponding sites. The researchers concentrated much on one irrigation site and dwelt on a few crops. Few irrigations need curves ware determined by proper modeling of irrigation load through agricultural data. The gap addressed adequately in this research was two pronged. Two models were

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

required to depict the problem. The agricultural model used to determine the Irrigation Water Needs (IWN) was the initial, required for specific crops grown at the corresponding irrigation site. In second phase, detailed analysis of pump model so that pump load profile matched with pump power. The uniqueness of this research was proper irrigation load modeling done in many crop situations as well as for different irrigation sites in Kenya[1]. The irrigation water needs modeled from the agricultural parameters [22] given in Equation 1 below.

$$Q = \frac{[\rho(0.46T_{mean}+8)K_c+P_p-P_e]*10^4*A_{land}}{10^3*T_{pump}} m^3/\text{s} \qquad (1)$$

The equivalent circuits as shown in Fig. 1 below [23] characterize induction Machines.

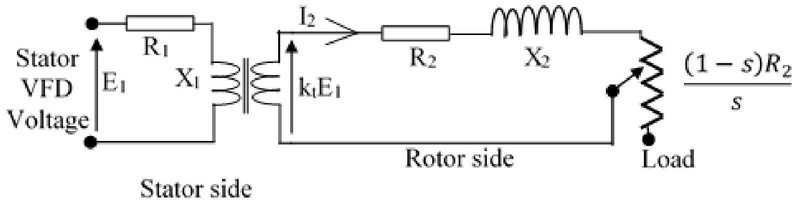

Fig. 1. Per-phase equivalent circuit of induction machine

Equation 2 below shows the corresponding load current. The output power is given in the form of $P=I^2R$ and can be shown to be as follows[1]

$$I_2 = \frac{sk_tE_1}{\sqrt{(R_2)^2+(sX_2)^2}} \qquad (2)$$

$$= N\,x\,\frac{3{k_t}^3E_1^2s(1-s)R_2}{[(R_2)^2+(sX_2)^2]x1000} \qquad (3)$$

$$P_{motor} = \frac{P_{pump}}{\eta_{motor}}$$

$$= \frac{\rho.g.H_{TDH}.Q}{\eta_{motor}\eta_{pump}\,x\,3.6\,x\,10^6} kW$$

$$= N\,x\,\frac{3{k_t}^3E_1^2s(1-s)R_2}{[(R_2)^2+(sX_2)^2]x1000} \qquad (4)$$

Following pump affinity laws it can be shown that [1]

$$\frac{P_1}{P_2} = \frac{\omega_1^3}{\omega_2^3} = \frac{k_{Q1}k_{H1}f_{e1}^3}{k_{Q2}k_{H2}f_{e2}^3} \qquad (5)$$

Energy source modeling was as shown in Equations 6, 7 and 8 below. An assumption was that H_{GHI} was 6.5 sun-hours in Kenya, an equatorial country

$$P_{wind} = \frac{\frac{1}{2}C_p\eta_{turbine}\rho_{air}AV^3}{1000} kW \qquad (6)$$

$$P_{solar} = \frac{A_{panel}\,x\,rx\,PRx\,H_{GHI}}{6.5} kW \qquad (7)$$

$$P_{motor} \leq P_{wind} + P_{solar} \qquad (8)$$

A_{panel} is solar panel area (m^2), $A_{turbine}$ is wind turbine blade area (m^2), and C_p is coefficient of performance of wind turbine (%). f_e is variable frequency (Hz), g is acceleration due to gravity (9.81kg/m^3), and H_{GHI} is solar irradiance (kW/m2). k_Q is discharge pumping constant, k_H is head pumping constant, N is number of irrigation

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Pumps (units), and $P_{deficit}$ is power deficit (kW) and P_e is precipitation (effective rainfall) (mm). $P_{generated}$ is power generated (kW), p_p is percolation (mm), PR is performance ratio of the solar system (%), $P_{utilized}$ is power utilized(kW), P_{wind} is power output of the wind turbine(kW), and r = yield factor of solar panels (%). V is wind speed (m/s), η_{motor} is pump efficiency (%), η_{pump} is pump efficiency (%), $\eta_{turbine}$ is turbine efficiency (%), ρ_{air} is the actual air density (kg/m)], and ρ_w= density of water (1000kg/m^3)

3 Methodology

In this research, three models were developed and used. They were a physical model, mathematical model, and MATLAB/Simulink models. The details of the models are as described in the following subtitles.

3.1 Physical Site Model

This was as shown in Fig. 2 was used. It was a typical physical irrigation site as postulated by [1]. It was possible to install at least solar PV panels and wind turbines in the sites selected. The optimum number, rating, and ratio of these components had been determined utilizing Hybrid Optimization Modeling for Electric Renewables (HOMER) software. The considered size of land was 10000 acres (4047Ha).

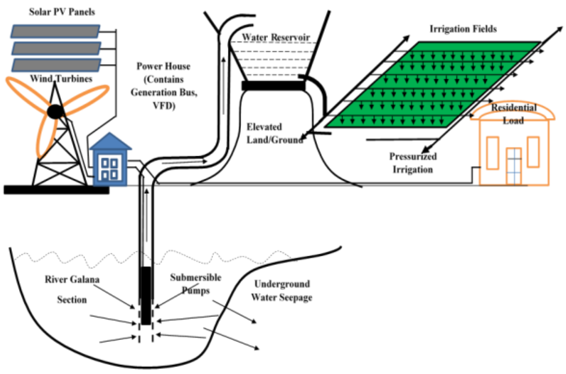

Fig. 2. Typical Model of the Irrigation Site

The figure above was extracted from [1], in the research for "*Optimized Optimized Hybrid Wind-Solar Energy System Structures For Irrigation Pump Load Sites In Kenya"*. This research conducted in the first phase where the optimal structure of wind and solar PV system corresponding to irrigation sites and crops was prerequisite.

3.2 Mathematical Model

The mathematical model for the research shown in Fig. 3 below. The upper part of the model (Fig. 3) represented the RES power generation, while the lower part represented the induction motor load. Note that the discharge required defined in the term $kQkHfe^3$ in the model was key point in the research. This term represented the Head (H) and Discharge (Q) as shown in affinity laws (Equation 5)[1]. The difference between the generated and utilized power gave the surplus or deficit. In adapted systems with stepped VFDs, the surplus or deficit expected to be perfect because of a perfect load curve fitting to DIL or RES curves was also key in this research. In a stepped VFD system, induction motor pumps that make the significant irrigation load, were not only switched according to the approximate number required (N) but also operated at a critical frequency (f_e) which was varied to consequently vary Q as demanded by irrigation water need (IWN) (Equation 1)

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

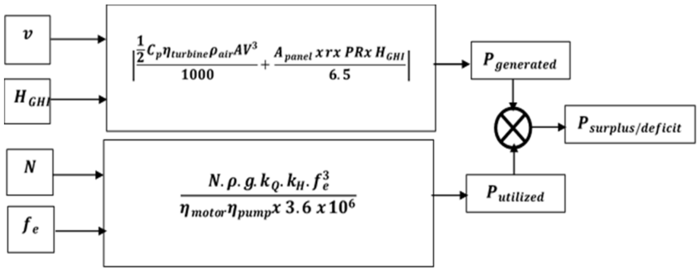

Fig. 3. The Mathematical Model

3.3 MATLAB/Simulink Model

The corresponding MATLAB/Simulink block and simulation diagrams shown in Fig.4 and Fig. 5 below were the operating models. On the left-hand side was the RES generation system whose output fed a common DC bus. A short transmission line used to evacuate the generated power to the load side was included. On the load side, the irrigation pumps switched ON in sequence as the VFD variable frequency output acted to control the speed of the pumps.

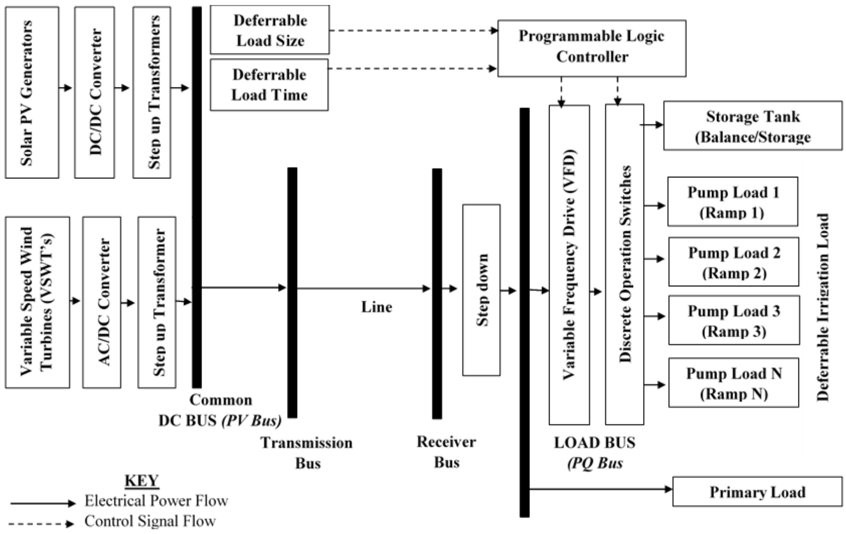

Fig. 4. The Block Diagram of MATLAB/Simulink Model

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

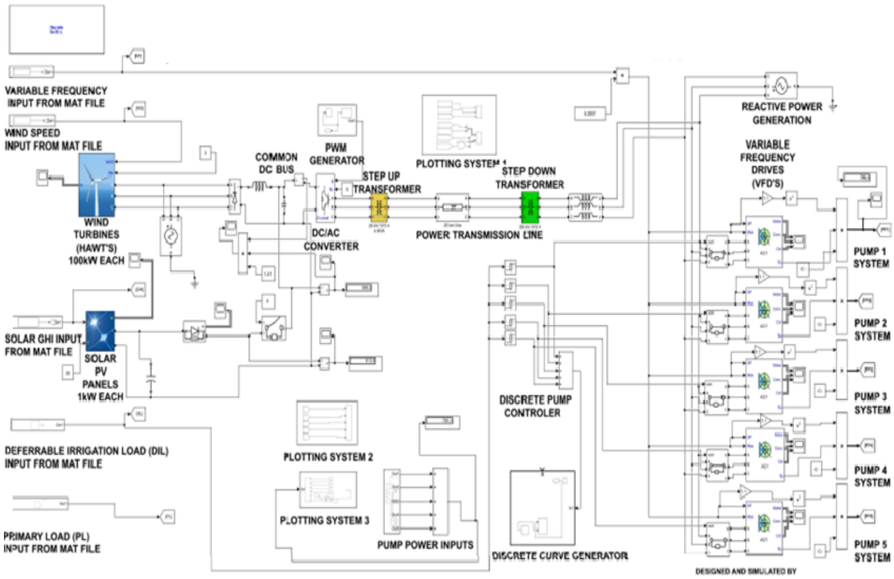

Fig. 5. The MATLAB/Simulink Simulation Model

3.4 Results

The models run on MATLAB/Simulink software for these two scenarios (i) one-site-many-crops scenario (Fig. 6) and (ii) five-sites-one crop scenario (Fig. 7). The results also shown were for discrete and VFD systems adapted to sufficient and insufficient energy resources (Fig. 8). The results in the figures showed that the adapted pump systems to DIL was a successful strategy. The adapted load curve (Red Curve) was observed to be between the anticipated DIL curve (Blue Curve) and the discrete pump load (Brown Curve). A curve fitting improvement from a discrete curve was therefore evident. There was a smoother transition between steps albeit with significant oscillations. Higher cyclic crops– crops that grown more than 3 times in a year–like spinach and radish were shown to have more stepped switching than low cycle crops like sugarcane. Cash crops for instance sugarcane and cotton had significantly stable peak demand compared to food crops such as maize beans and spinach. In all cases, the adapted pump load was lowest in the period around the 26th week. This was the period between May and August were coincidentally there was significant precipitation (Rainfall) at the Galana-Kulalu site. This in effect reduced the irrigation water need. The reservoir levels had the greatest oscillations or instability whenever there was a peak demand. There was no notable relationship between the variable frequency curve and reservoir levels. There was no relationship between the size of the load and variable frequency since it was determined based on the critical load at each point in the system. There was a near-perfect curve fit when a stepped VFD pump system acted to adapt the load to sufficient and insufficient RES (Fig. 8).

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Table 1. Table of Figures for MATLAB/Simulink simulation results (one-site-six-crop scenario)

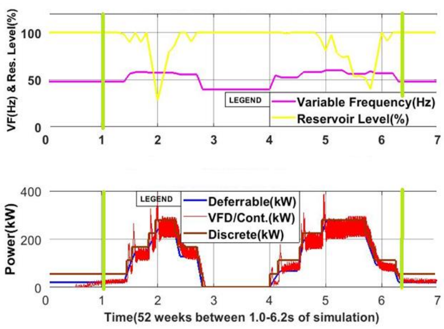

Fig. 6(a). Galana-Kulalu: Maize Irrigation

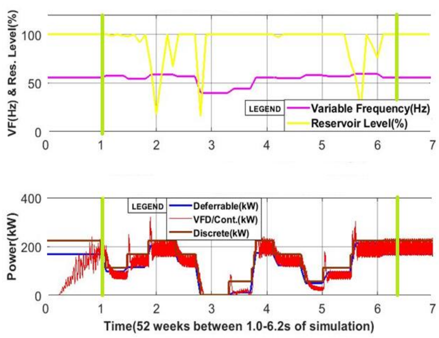

Fig. 6(b). Galana-Kulalu: Beans Irrigation

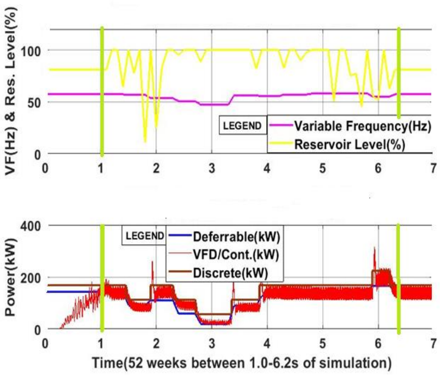

Fig. 6(c). Galana-Kulalu: Sugarcane Irrigation

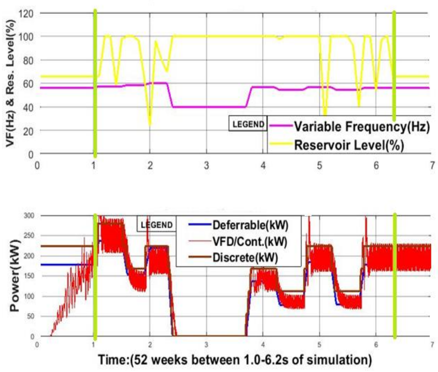

Fig. 6(d). Galana-Kulalu: Radish Irrigation

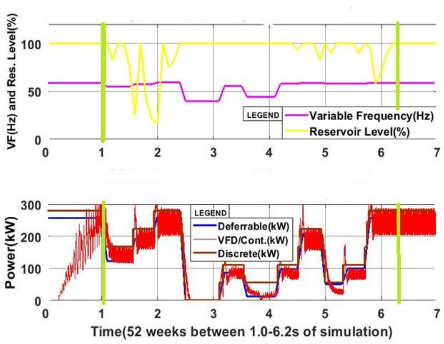

Fig. 6(e). Galana-Kulalu: Spinach Irrigation

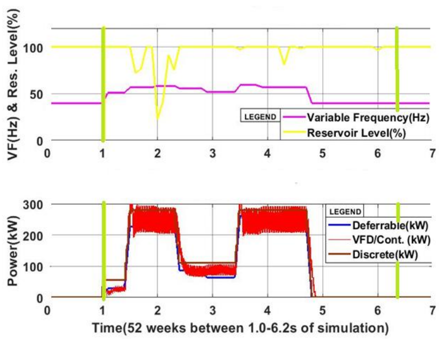

Fig. 6(f). Galana-Kulalu: Cotton Irrigation

Note that the Galana-Kulalu: Maize Irrigation does not appear in the following set of results (Fig. 7.) because it is the common scenario between the two sets of figures.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Table 2. Table of Figures for MATLAB/Simulink simulation results (five-site-one-crop scenario)

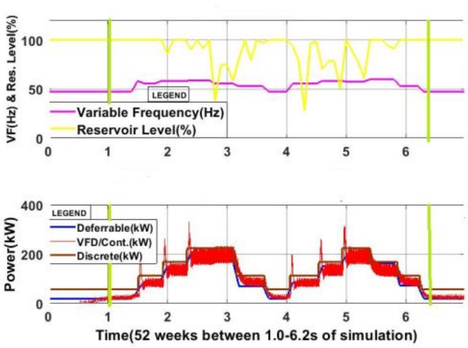

Fig. 7(a). Lotikipi: Maize Irrigation

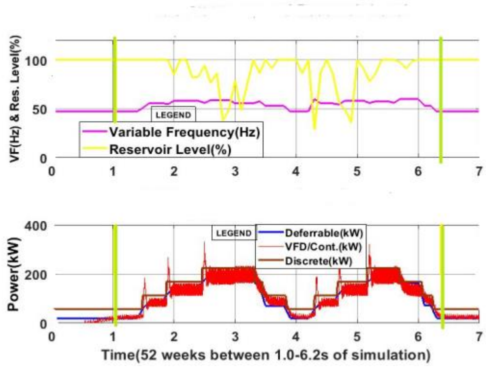

Fig. 7(b). Perkerra: Maize Irrigation

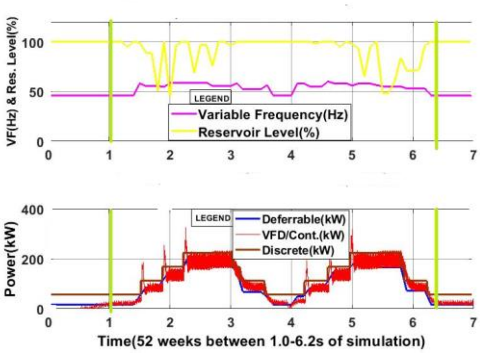

Fig. 7(c). Rahole: Maize Irrigation

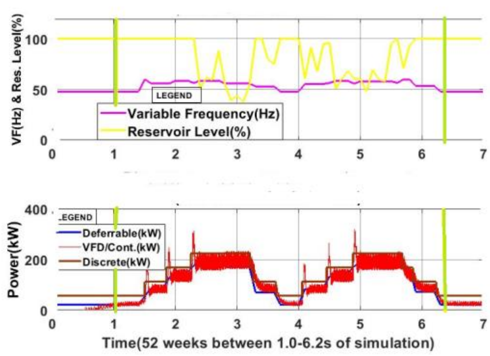

Fig. 7(d). Wei Wei: Maize Irrigation

Table 3. MATLAB/Simulink simulation results in sufficient and insufficient RES conditions

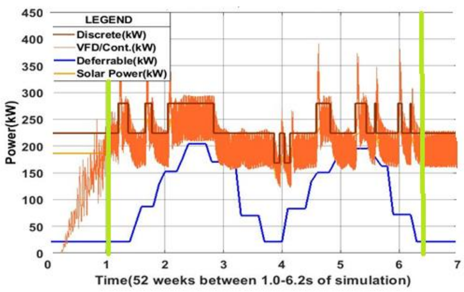

Fig. 8(a). Wei Wei: Maize Irrigation in sufficient (scaled-up) solar PV

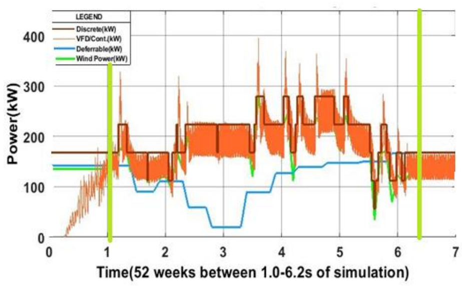

Fig. 8(b). Galana-Kulalu: Sugarcane Irrigation in sufficient (scaled-up) wind power

Journal of Digital Food, Energy & Water Systems [JD-FEWS]

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

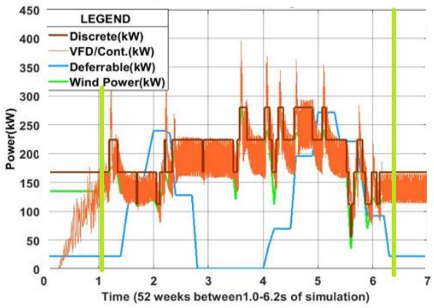

Fig. 8(c). Galana-Kulalu: Maize Irrigation in insufficient(scaled-down) wind power

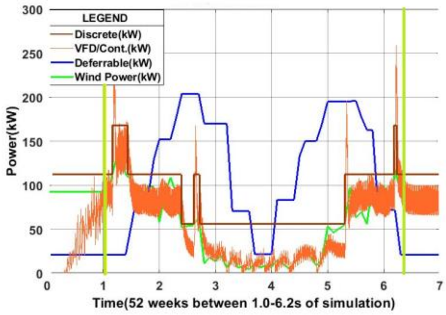

Fig. 8(d). Wei Wei: Maize Irrigation in very low (scaled down too much) wind power

4 Analysis

The system variable frequency successfully maintained itself between 40Hz and 60Hz as shown by the Variable Frequency (VF) curve in Fig. 6 and Fig.7. The reservoir level indication was unique for each case. The observed disturbance on reservoir levels was great and unique during peak demands in each case. Highly cyclic crops like spinach and radish had more steps compared to lower cyclic crops like sugarcane and cotton. The longer cyclic crops had stable energy requirements compared to short cycle crops.

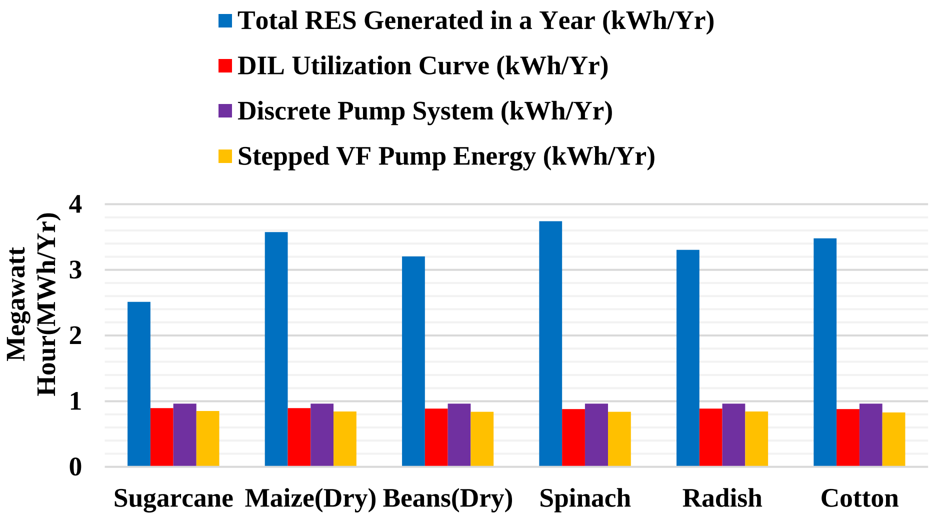

Fig. 9(a). Results analysis for discrete and stepped VFD pump systems adapted to DIL(one-site-six-crop-scenario). The one-site is the Galana-Kulalu Irrigation Site

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

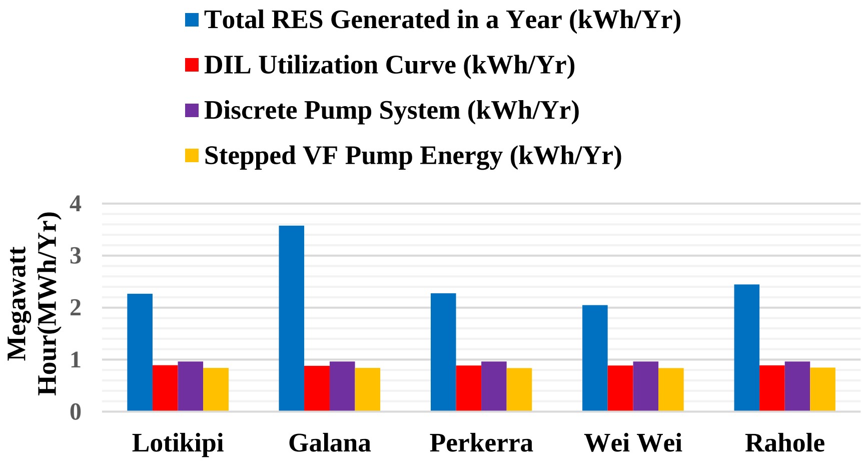

Fig. 9(b). Results analysis for discrete and stepped VFD pump systems adapted to DIL(five-site-one-crop-scenario). The one-crop is maize.

Fig. 9(a) below showed analysis of the results for generated verses utilized energy for one-site-six-crop-scenario. It was clear that the generated energy was very high as compared to utilized energy. The generated energy for spinach irrigation system was the highest (3.7MWh/Yr) compared to the lowest, that of sugarcane (2.5MWh/Yr). The average generated energy was 3.3MWh/Yr. The utilization in terms of anticipated DIL, discrete pump system and adapted (stepped frequency) pump system were all between 0.8-1MWh/Yr therefore indicating a surplus of slightly over 2.7MWhr/Yr. **Fig. 9(b)** shows the five-site-one-crop-scenario, where the crop referred to here is maize. Galana-Kulalu site had the possibility of very high renewable energy generation (3.6MWh/Yr) and corresponding highest surplus (2.7MWH/Yr) compared to a Wei Wei site low of 2.0MWh/Yr. The average RES possible to generate at the Galana-Kulalu site was approximately 3.30MWhrs while the possible average utilized energy was 0.89MWhrs in a given year. This meant that there was a generation surplus of 2.41 MWhrs. For the other sites, it was 3.22MWhrs against an anticipated utilization of 0.96 to yield an expected surplus of 2.26MWhrs. The surplus created by using the adapted load through stepped VFD was higher than that of the discrete system in each scenario above.

Fig. 10(a) below shows the analysis of the results for the one-site-six-crop-scenario and. The analysis showed that there was a significant improvement in the use of VFDs as opposed to discrete-only systems. In all cases studied the stepped frequency strategy was much better that the discrete system. For the one-site-six-crops scenario, the variable frequency curve fitting to DIL was 96.9% against the discrete system having 91.3%. Fig. 10(b) showed the case of five-site-one-crop scenario. There was a slight improvement in stepped variable frequency of 93.9% against 91.4% when irrigation sites were changed. An overall improvement of 95.4 curve fit was observable against a 91.4% curve fit for the discrete-only system. The location of RES irrigation system significantly affected the surplus energy generation.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

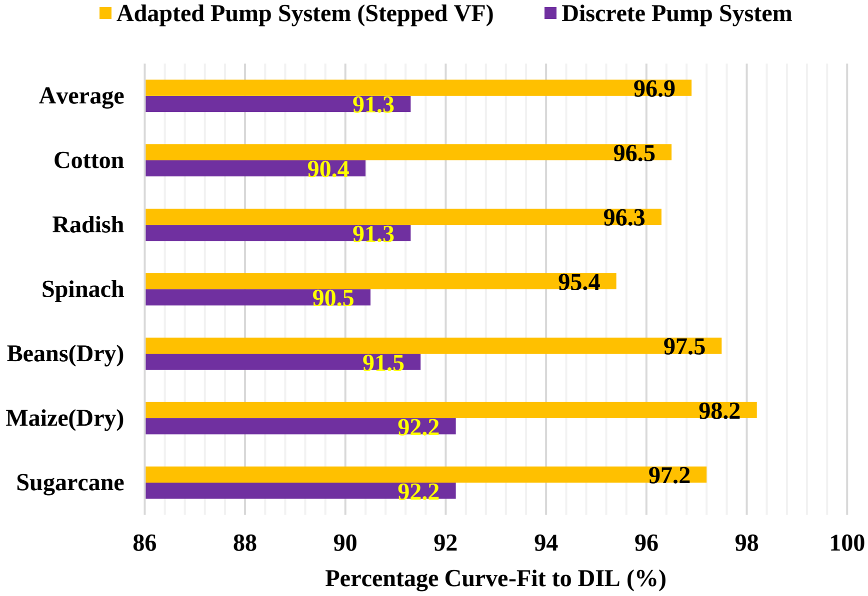

Fig. 10(a). Results analysis for discrete and stepped VFD pump systems adapted to DIL

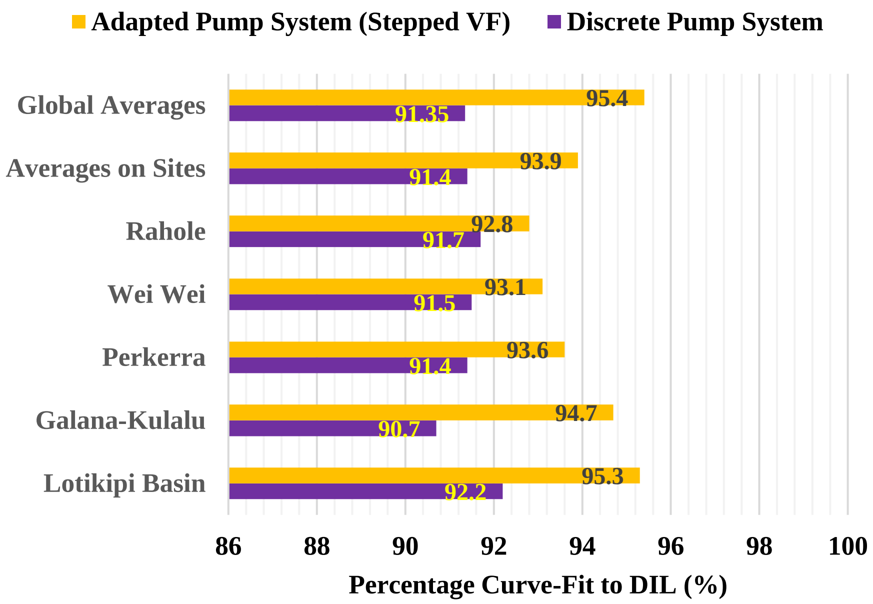

Fig. 10(b). Results analysis for discrete and stepped VFD pump systems adapted to DIL

5 Conclusion

The adapted irrigation pump system in the wind and solar PV energy systems through the stepped variable frequency drives was an excellent strategy in ensuring that the irrigation pump load was a near-perfect fit (95.4%) to the anticipated Deferrable Irrigation Load (DIL). This was an improvement of 4.5% as compared to discrete only system having 91.35% curve fit. The results showed that it was not tenable to scale down solar PV or wind energy systems to reduce the surplus energy in irrigation energy systems. The scale-down strategy in effect did not adequately serve the irrigation load, in other words, it was not possible to irrigate satisfactorily with a scaled-down energy system rather than an optimized one. This was because pumping of irrigation water was schedulable or deferrable event, yet the RES were not. In an irrigation system, a curve-fitting technique to RES with adapted pump load through VFDs was excellent meaning that this strategy was best applicable as a demand-side management strategy for a power system. For curve fitting to RES, the improved efficiency of energy utilization meant that energy generated was readily utilizable in irrigation with a high surplus, which was available for other agricultural uses or energy export. The research therefore recommended additional energy-intensity agricultural uses of RES such as electric drying and other value-added farm processes. Another recommendation is investment in large food processing factories near potential irrigation sites if RES harnessed for large-scale irrigation farms was possible. Other high-energy use solutions like in the production of hydrogen alongside irrigation plans were quite considerable. Where it is not possible, a combination of irrigation systems with large water users, for example, a municipal or city or an energy buying utility company entity was sustainable so that excess energy was utilizable for pumping water, sewerage, or direct use instead.

6 Acknowledgment

We would like to acknowledge the support we got from Mr. Meshaki Shake. Mr Shake was helpful in the installation and maintenance of simulation softwares and was available any time I faced a challenge. We would like to appreciate EssenSolar (FSP Group (NGO) in India); Comax Solution (Trina Solar Ltd in China) Argolabe Ingeniena(a private company in Spain); and Pedrollo (a private company in Italy) for availing product information and resources online. Others are NIA and NIB Government irrigation bodies in Kenya. Their product information or data were valid and easily accessible online. Kenya Society of Environmental, Biological and Agricultural Engineers (KeSEBAE), TUM Multi-disciplinary conferences, and Institution of Engineers of Kenya (IEK) for giving me opportunity to disseminate findings in their conferences.

7 References

[1] S. Soshyo, M. Saulo, and L. Mukhongo, "OPTIMIZED HYBRID WIND-SOLAR ENERGY SYSTEM STRUCTURES FOR IRRIGATION PUMP LOAD SITES IN KENYA," *J. Eng. Agric. Environ.*, vol. 8, no. 3, 2022, doi: 10.37017/jeae.v8i3.28.

[2] S. Mandelli, J. Barbieri, L. Mattarolo, and E. Colombo, "Sustainable energy in Africa: A comprehensive data and policies review," *Renew. Sustain. Energy Rev.*, vol. 37, pp. 656–686, 2014, doi: 10.1016/j.rser.2014.05.069.

[3] A. N. Al-shamani *et al.*, "Design & Sizing of Stand-alone Solar Power Systems A house Iraq," *Des. Sizing Stand-alone Sol. Power Syst. A house Iraq Ali*, pp. 145–150, 2013.

[4] A. Ahmad and S. Khan, "Water and Energy Scarcity for Agriculture: Is Irrigation Modernization the Answer?," *Irrig. Drain.*, 2017, doi: 10.1002/ird.2021.

[5] B. Mainali, S. Pachauri, N. D. Rao, and S. Silveira, "Assessing rural energy sustainability in developing countries," *Energy Sustain. Dev.*, vol. 19, no. 1, pp. 15–28, 2014, doi: 10.1016/j.esd.2014.01.008.

[6] National Irregation Board, "Galana Kulalu Irrigation Development Project," *nib.or.ke*, 2018.

[7] M. Hiller *et al.*, *Solar pumping for irrigation: Improving livelihoods and sustainability*, no. June. 2016.

[8] I. Boldea, "Electric generators and motors: An overview," *CES Trans. Electr. Mach. Syst.*, vol. 1, no. 1, 2020, doi: 10.23919/tems.2017.7911104.

[9] R. S. Krishnan *et al.*, "Fuzzy Logic based Smart Irrigation System using Internet of Things," *J. Clean. Prod.*, vol. 252, 2020, doi: 10.1016/j.jclepro.2019.119902.

[10] A. Moubarak, G. El-Saady, and E.-N. A. Ibrahim, "Variable Speed Photovoltaic Water Pumping Using Affinity Laws," *J. Power Energy Eng.*, vol. 05, no. 11, 2017, doi: 10.4236/jpee.2017.511005.

[11] N. Naval and J. M. Yusta, "Optimal short-term water-energy dispatch for pumping stations with grid-connected photovoltaic self-generation," *J. Clean. Prod.*, vol. 316, 2021, doi: 10.1016/j.jclepro.2021.128386.

[12] W. Wu, A. R. Simpson, H. R. Maier, and A. Marchi, "Incorporation of Variable-Speed Pumping in Multiobjective Genetic Algorithm Optimization of the Design of Water Transmission Systems," *J. Water Resour. Plan. Manag.*, vol.

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

138, no. 5, 2012, doi: 10.1061/(asce)wr.1943-5452.0000195.

[13] M. C. Morani, A. Carravetta, G. Del Giudice, A. McNabola, and O. Fecarotta, “A comparison of energy recovery by pATs against direct variable speed pumping in water distribution networks,” *Fluids*, vol. 3, no. 2, 2018, doi: 10.3390/fluids3020041.

[14] V. B. da S. Baptista, J. I. Córcoles, A. Colombo, and M. Á. Moreno, “Feasibility of the use of variable speed drives in center pivot systems installed in plots with variable topography,” *Water (Switzerland)*, vol. 11, no. 10, 2019, doi: 10.3390/w11102192.

[15] I. A. Abdaljlel, A. Y. Georgi, and A. H. Shaker, “Study The advantage of variable speed pumps Economically in pumping water lines using genetic algorithms,” *Assoc. Arab Univ. J. Eng. Sci.*, vol. 27, no. 3, 2020, doi: 10.33261/jaaru.2020.27.3.014.

[16] B. D. Vick, “Developing a hybrid solar/wind powered irrigation system for crops in the great plains,” in *39th ASES National Solar Conference 2010, SOLAR 2010*, 2010, vol. 1.

[17] I. Widiastuti and D. S. Wijayanto, “Developing a hybrid solar/wind powered drip irrigation system for dragon fruit yield,” in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 180, no. 1. doi: 10.1088/1757-899X/180/1/012034.

[18] H. Murty and M. F. Fauzan, “Automated Water Irrigation System for Urban Farming,” *MATEC Web Conf.*, vol. 335, 2021, doi: 10.1051/matecconf/202133503004.

[19] L. J. Hagen and M. Sharif, “Wind-Powered Irrigation Tailwater System: Sizing the Wind Turbine and Storage Pit,” *Trans. ASAE*, vol. 24, no. 1, 1981, doi: 10.13031/2013.34207.

[20] M. Harries, “Disseminating wind pumps in rural Kenya - Meeting rural water needs using locally manufactured wind pumps,” *Energy Policy*, vol. 30, no. 11–12, 2002, doi: 10.1016/S0301-4215(02)00060-5.

[21] T. Aized, S. M. Sohail Rehman, S. Kamran, A. H. Kazim, and S. Ubaid ur Rehman, “Design and analysis of wind pump for wind conditions in Pakistan,” *Adv. Mech. Eng.*, vol. 11, no. 9, 2019, doi: 10.1177/1687814019880405.

[22] S. Song and J. Niu, “Potential assessment on wind-powered water pumping for irrigated agriculture in Southern Xinjiang,” *Nongye Gongcheng Xuebao/Transactions Chinese Soc. Agric. Eng.*, vol. 37, no. 2, 2021, doi: 10.11975/j.issn.1002-6819.2021.2.015.

[23] R. Sridevi, C. Kumar, P. Suresh, S. Ganesan, S. Subramanian, and A. Suresh, “Development of a pedagogical framework to analyze the performance of induction machines,” *Int. J. Electr. Eng. Educ.*, vol. 58, no. 2, 2021, doi: 10.1177/0020720919828993.

8 Authors

Samson Sing’oei Soshyo is a member of Faculty of Engineering and Technology at Technical University of Mombasa. He holds a Bachelor of Technology Degree (B. Tech, Moi) in Electrical and Communications Engineering and a Master of Technology (M. Tech, TUM) Degree in Sustainable Energy Engineering. He has over 20 years’ experience as a career competency-based trainer for TVET programmes in the Institution. He therefore facilitates training for both Diploma and Undergraduate students at the Institution, mainly in the areas of green building, energy, and electrical power systems. His main passion is sustainable energy engineering especially at the nexus between energy food and water, and practices on the same areas. Address: P.O. Box 90420-80100 Mombasa; E-Mail: ssoshyo@tum.ac.ke

Sameer Kamrudin Bachani, is the Dean of the Faculty of Engineering and Technology at the Technical University of Mombasa, He is a senior lecturer in the department of Mechanical Engineering. He holds a Doctor of Philosophy in Material Science field of National Taiwan University of Science and Technology. He specifically researches currently on high operating temperature metals. Address: P.O. Box 90420-80100 Mombasa. E-Mail: sameerbachani@tum.ac.ke

Michael Juma Saulo, is a Senior Lecturer in the Faculty of Engineering and Technology, the Department of Electrical and Electronic Engineering at the Technical University of Mombasa. He holds a Doctor of Philosophy in Power Systems Design and Analysis of University of Cape Town. His current research are in power systems and renewable energy Address: P.O. Box 90420-80100 Mombasa. E-Mail: michaelsaulo@tum.ac.ke

JDFEWS 4 (2): 57-71, 2023
ISSN 2709-4529

Lawrence Manyonge Mukhongo is a Senior Lecturer in Faculty of Engineering and Technology, the Department of Electrical and Electronic Engineering at the Technical University of Mombasa. He holds a Doctor of Philosophy in Industrial Manufacturing. His current researches are in Mechatronic Engineering. Address: P.O. Box 90420-80100 Mombasa. E-Mail: mukhongo@tum.ac.ke