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Performances Analysis and Comparison of Active and Hybrid Harmonic Filter in Photovoltaic Water Pumping System

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***Abstract* — As an agriculturally based country, many rivers pumping stations are implemented in Myanmar. Currently, these pumping stations are operated with utility supply or diesel engines. For reliable energy supply and energy cost saving, the solar powered river pumping stations are now carried out in Myanmar. Most of these pumping stations are located at the dry zones especially at Magway, Mandalay and Sagaing Divisions. The main problem with solar powered river pumping station is the harmonic induced due to DC/DC boost converter and three phase inverters. Harmonics are the important problem in solar river water pumping system as they can shorten the life span of pumping motors and vibrations. Thus, harmonic filters become the main function of these system. In this research, the harmonic mitigation for Kanni river pumping system is executed using active and hybrid harmonic filter and their performances are compared. In this work, solar river water pumping system is designed firstly, and then modelled and simulated using MATLAB/Simulink. Harmonic contents and mitigation performances of each filter are analysed using Fast Fourier Transform (FFT) tool.**

Keywords— Photovoltaic water pumping system, Boost converter, Three phase inverter, Harmonic distortion, Harmonic filter.

I. INTRODUCTION

Agricultural technology is changing rapidly. There are numerous agricultural works with solar PV applications. Solar water pumping is the most beneficial application for livestock and crops especially for remote rural area. The solar PV powered water pumping systems (PVWPS) consists of two main sections: the PV system and pumping system. PVWPS consists of different components and parts associated with different fields of engineering like mechanical, electrical, electronics, computer, control and civil engineering. The present PVWPS researches are to make the system more efficient and cost-effective to meet water-pumping needs of human, livestock and irrigation [1].

In recent years, the applications of solar PV become widespread in various application areas. Their effectiveness is more significant for remote and isolated locations. The most promising condition of PV application is water pumping for livestock, cultivation and domestic used in rural area. PV water pumping systems are more suitable for the remote and isolated regions where the power supply from the grid is unavailable. The ground water or river water is to be pumped while radiation is obtained and stored in the ponds and tanks for future use or direct supply to the farms. The main advantages of photovoltaic water pumping systems are low maintenance, no fuel cost, ease of installation, reliability on the source and matching between the water requirement and PV power available [1].

The main problem with solar water pumping station is the harmonic induced due to DC/DC boost converter, three phase inverter and non-linear loads. Harmonic distortion can reduce system performance and efficiency of water pump motor. To overcome harmonic distortion of photovoltaic water pumping system with high efficiency and high-quality power supply, harmonic filters are needed to install in this system.

In this paper, harmonic mitigation for solar water pumping system is presented using active and hybrid harmonic filter. The harmonic mitigation performances are compared. The design calculations for active and hybrid filter are also described in detail. The harmonic analysis is done with Fast Fourier

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Transform (FFT) tools. To observe content and performance, Institute of Electrical and Electronic Engineers (IEEE) 519 standards are used [2]. The modelling and simulations are done with MATLAB/Simulink. According to the simulation results, the harmonic mitigation performance of hybrid filter is superior to active filter.

II. PHOTOVOLTAIC WATER PUMPING SYSTEM

In solar PV applications, water pumping is the easiest and the most effective one for remote rural area. Solar water pumping systems can supply water requirements for irrigation, livestock and domestic uses in these regions. The largest barrier for solar water pumping application is its large capital investment cost. According to the detailed research and analyses, the payback period is short and can give many benefits for application. Comparing with other water pumping systems such as diesel engine pumps and electric motor pumps, there is no running cost, fuel cost and negligible maintenance cost in solar water pumping system. Comparing with the water pumping by windmill, the initial cost is nearly the same but solar water pumping systems are more reliability and less maintenance [3].

In electricity generation by PV arrays, there are no moving parts and thus no wearing problems. The solar radiant energy of the sun rays is converted to direct current (DC) electricity and is supplied to pump motor for pumping of water from the ground water source or rivers. In solar water pumping system, the size of pump and motor should be carefully selected so that the adequate water can be supplied to irrigation or other purposes. In the same way, the size of PV system must be wisely selected based on the available irradiation of the specific location, and power requirement of pump motor [3].

III. HARMONIC MITIGATION TECHNIQUES

A. Active Harmonic Filter

In active harmonic filter, the filter injects the current which is equal in magnitude and opposite in polarity to the load current. This type of filter creates a low impedance path for the distorted currents except that at fundamental frequency. Actually, it acts as a current source supplying equal and opposite currents of distorted current components.

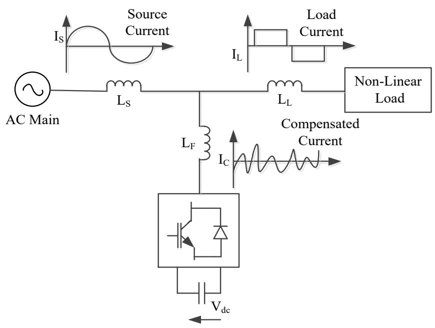


Fig. 1. Components and connection scheme in shunt active harmonic filter.

Compared to passive filters, active filters can overcome the weaknesses of passive filter. Active power filters classified into two types. They are shunt active power filter and series active power filter. This paper discusses about to remove the current harmonics, so only shunt active filters are employed. The main elements of active filter are voltage source converter (VSC) comprising power transistors. Figure 1 shows the basic scheme of shunt active power filter which compensate load current harmonics by injecting equal but opposite harmonic compensating current [4].

B. Hybrid Harmonic Filter

Figure 2 shows the hybrid combination of passive and active filters. The main purpose of the hybrid combination is to reduce the cost of charges at active filter and to improve the harmonic mitigation performance compared to passive filter. Passive filters are used to suppress the most relevant harmonics of the load, and active filters are used to improve the performance of passive filters or suppress other harmonic content. As a result, the performance of the active filter is degraded and passive filter problems (such as resonance with the source impedance) are mitigated. In summary, it reduces overall costs without compromising [4].

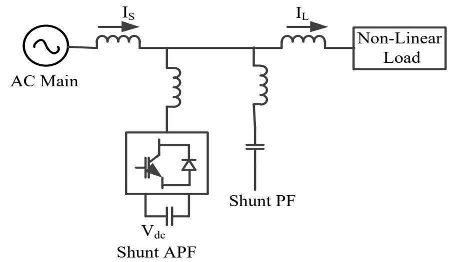


Fig. 2. Hybrid harmonic filter (shunt passive and shunt active).

IV. CASE STUDY AND MODELING OF PHOTOVOLTAIC WATER PUMPING SYSTEM

In this paper, solar river water pumping system allocated in Kanni village, Min Bu Township, Magway Divisions, in Myanmar will be carried out. Kanni solar river water pumping system is located at latitudes 19º 59' 16" N and longitudes 95º 11' 32" E. The site covers 757 acres. For the implementation of this research, the data collection is carried out at December, 2022. In Kanni, 132 kW (175 HP) pump motor is used. The capacity of solar PV system is about 213 kW. River water is absorbed by a 12-inch iron pipe line to the main reservoir of calm water that is 87 feet above the water level.

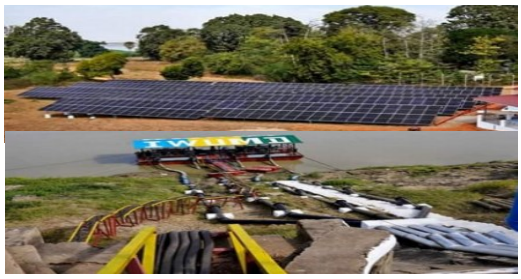


Fig. 3. Kanni solar river pumping system for irrigation.

Then, river water is distributed along 2.62 miles main drain and 3.69 miles arm drain for agricultural land of 757 acres. Figure 3 shows Kanni solar river pumping system and PV array installation. Figure 4 illustrates yearly solar radiation of Kanni village.

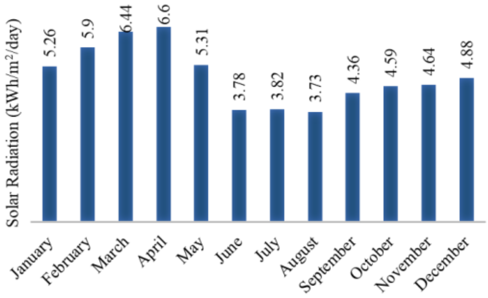


Fig. 4. Yearly Solar Radiation of Kanni Village.

In Kanni solar river pumping system, the solar module model is "SunPower SPR 320E- WHT-D". There are 663 numbers of PV modules having power rating of 320.542 W. There are 51 strings with 13 modules per strings. The power output from the PV system is used to operate the river water pumping motor. The type of pump motor is squirrel cage induction motor with three phase input. The detail specifications for pump motor are as follow:

Power rating = 132 kW
Voltage rating = 400 V
Frequency = 50 Hz
Rated Speed = 1480 rpm
Numbers of pole = 4 poles
Rated torque = 851.8 Nm
Power Factor = 88.5 % = 0.885

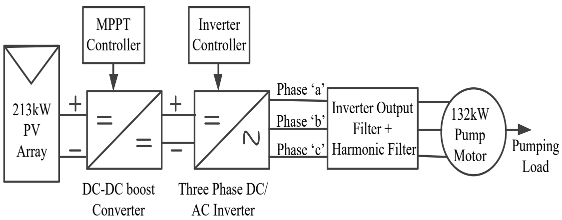


Fig. 5. Block diagram of Kanni solar river pumping system for irrigation.

Figure 5 shows the system block diagram of Kanni solar river pumping system for irrigation. The main components in the system are the PV array, DC/DC boost converter with MPPT controller, three phase DC/AC inverter, inverter output filter and motor load. For the modelling of the system, the required parameters for each component are formerly calculated. According to the calculation results, the parameters for each component are as follow:

Inductance of boost converter = 5.341 mH
Capacitance of boost converter = 5.997 mF
Output inductance of inverter = 419.9 µH
Output capacitance of inverter = 132.4 µF
Switching frequency = 5kHz

In Simulink model, the calculated values are used. In practical applications, the available components should be used with series/parallel connection as necessary to obtain these values. Figure 6 illustrates the Simulink model of solar river pumping system.

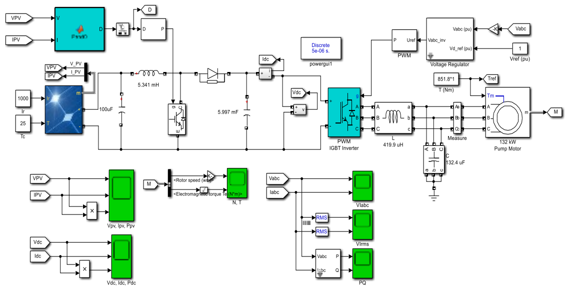


Fig. 6. Simulink model of photovoltaic water pumping system.

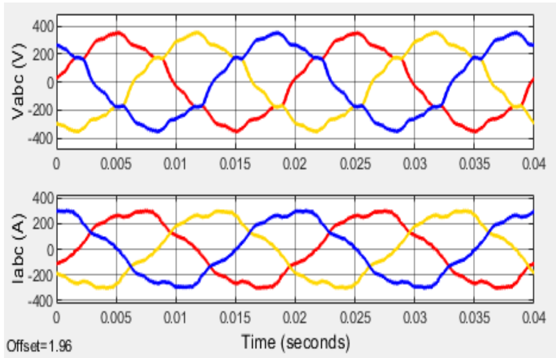


Fig. 7. Inverter output voltage and current waveforms without harmonic filter.

In Fig. 7, the inverter output voltage and current are distorted and rich in harmonic since the use of boost converter and inverter switches cause the non-linear load function at the motor terminal. In the operation of three-phase AC motors, the motor performances i.e., starting torque, break down torque, starting current, the output speed and vibration are largely related to the form factor of input AC supply. Thus, to operate the pump motor efficiently, these distorted waves are necessary to improve with suitable harmonic filtering.

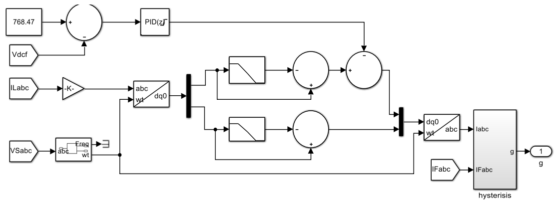
V. CALCULATIONS FOR PARAMETERS OF HARMONIC FILTERS

A. Calculation of Active Harmonic Filter Parameter

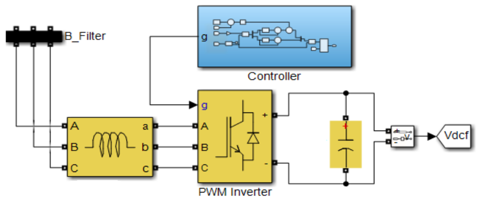
For the modelling of active harmonic filter, the circuit parameters are calculated and the results are shown in Table I [5]. The simulation model for shunt active filter is shown in Fig. 8.

Table I: Parameter of the system considered for shunt active filter.

Parameter	Value
DC capacitor voltage	768.47 V
DC bus capacitor	4.688 mF
AC inductor	463.32 µH



(a)



(b)

Fig. 8. Shunt active filter: (a) Control system and (b) Simulink model.

B. *Calculation of Hybrid Harmonic Filter Parameter*

To calculate design parameters of hybrid harmonic filter, it is needed to calculate both shunt passive and active harmonics filters. The simulation model for hybrid filter is shown in Fig. 9.

Design of Shunt Passive Harmonic Filter

f = 50 Hz, Q_c = 69.5 kVAR, Q = 50, V_{ph} = 230V

The design parameters for shunt passive filter component of hybrid harmonic filter with four harmonic orders can be carried out as shown in Table II [6].

Table II: Parameter for shunt passive filter.

Parameters	Harmonic Number			
	5^{th}	7^{th}	11^{th}	13^{th}
Capacitor (mF)	1.05	1.05	1.05	1.05
Inductor (H)	3.86×10^{-4}	1.969×10^{-4}	7.998×10^{-5}	5.749×10^{-5}
Resistor (mΩ)	12.13	8.66	5.528	4.696

Design of Shunt Active Harmonic Filter

f = 50 Hz, Q_c = 920VAR, Q = 50, V_{ph} = 230V

The design parameters for shunt active filter component of hybrid harmonic filter can be carried out as shown in Table III.

Table III: Parameter for shunt active filter.

Parameter	Value
DC capacitor voltage	768.47 V
DC bus capacitor	60.07μF
AC inductor	35.01mH

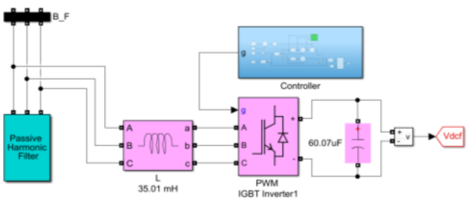
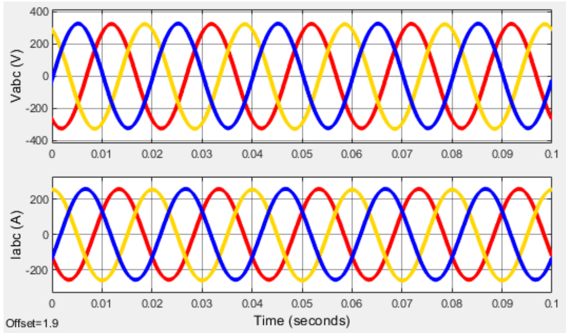


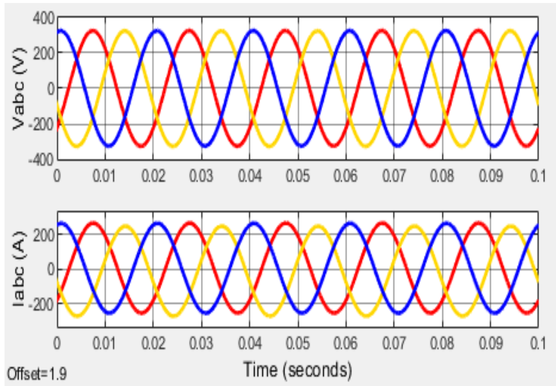
Fig. 9. Hybrid harmonic filter.

VI. MODELING AND SIMULATION RESULTS ANALYSIS

To compare the performance of each harmonic filter, the simulations are carried out by connecting the harmonic filters at motor terminals. Figure 10 shows the voltage and current waveforms with active and hybrid harmonic filter.



(a)



(b)

Fig. 10. Inverter output voltage and current waveforms: (a) with active filter (b) with hybrid filter.

For the control of motor output speed and torque, direct and quadrature (DQ) control method is used with Proportional plus integral (PI) controller. The proportional gain is set as 0.04 and the integral gain is set as 50. In case of shunt active harmonic filter, DQ control is used with proportional gain 0.05 and integral gain with 1. The pump load is set as the torque input with 851.8 Nm which correspond to the motor output power of 132kW. As shown in Figure 10, the voltage and current waveform distortions are reduced with active and hybrid harmonic filter. The mitigation performance of active filter is better than that of hybrid filter.

The waveform, harmonic contents and THD of voltage and current with active harmonic filter are shown in Fig. 11 and 12. For harmonic analysis, Fast Fourier Transform (FFT) tool of Graphic User Interface (GUI) in Simulink is used. For harmonic analysis, three cycles of corresponding waves are used. Harmonic analysis is carried out for 2000 Hz frequency.

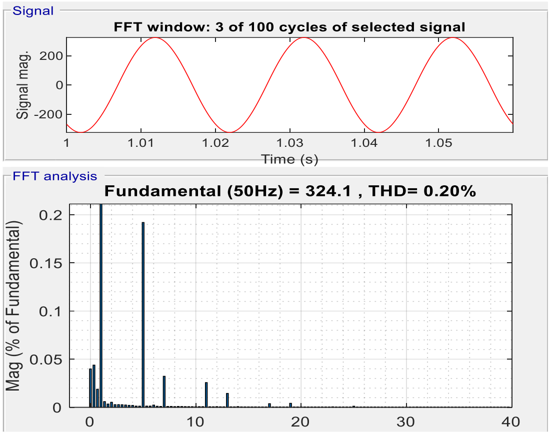


Fig. 11. Waveform, harmonic contents and THD of voltage with active harmonic filter.

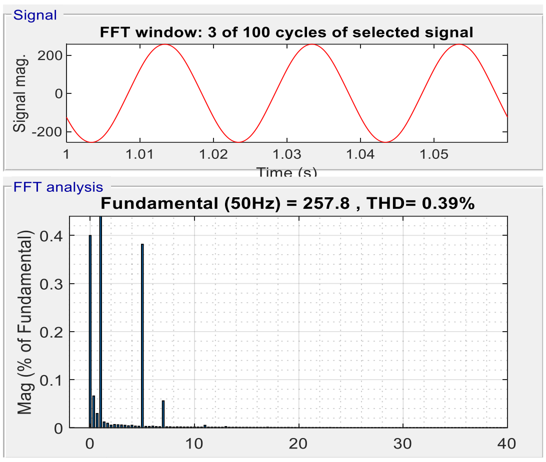


Fig. 12. Waveform, harmonic contents and THD of current with active harmonic filter.

As shown in Fig. 13 and 14, the voltage and current waveform distortions are reduced with hybrid harmonic filters. For harmonic comparisons, the FFT analysis is done for each waveform and the results are shown in Table IV.

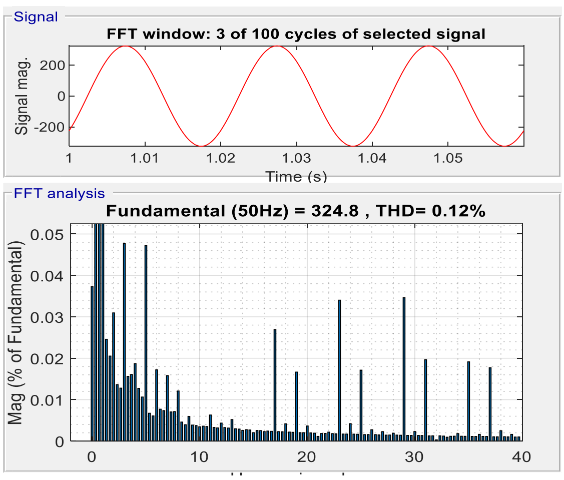


Fig. 13. Waveform, harmonic contents and THD of voltage with hybrid harmonic filter.

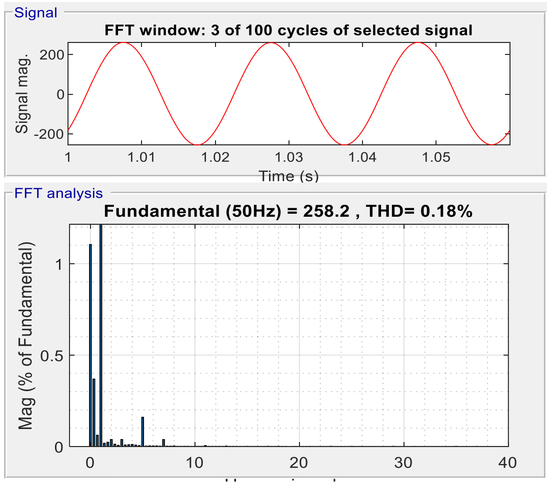


Fig. 14. Waveform, harmonic contents and THD of current with hybrid harmonic filter.

Table IV: Comparison for harmonic distortions.

	Voltage Waveform		**Current Waveform**	
	THD (%)	***Fundamental Component (V)***	***THD (%)***	***Fundamental Component (A)***
Without Filter	9.35	325.6	9.27	292.5
With Active	0.2	324.1	0.39	257.8
With Hybrid	0.12	324.8	0.18	258.2

The IEEE standard for THD of voltage is 8 % and current is 5 %. Without filters, both voltage and current distortions are large and greater than IEEE limits. With active harmonic filter, the distortions are reduced and within the limits. In case of hybrid filter, the harmonic distortions are negligible. The fundamental voltage and current components are nearly the same.

VII. CONCLUSION

In the present days, the PVWPS become a major pumping method in developing countries to supply water for drinking and irrigation purposes. The research opportunities in the field of PVWPS have also been presented in this paper. PVWPS has the great potential in Myanmar because of its geo-graphical location. The major problem with solar water pumping system is its harmonic distortion that can reduce system performance and efficiency of water pump motor. From the comparison of results with harmonic standard, the harmonic distortions of PVWPS are large and the suitable filters should be used for the proper operation of the system. In this paper, harmonic reduction is done using active and hybrid harmonic filter. According to the simulation results, the performance of hybrid filter is much better than that of active filter. With both harmonic filters, the harmonic contents can be reduced to the acceptable limits according to IEEE standards. For further study, the cost comparison of the active and hybrid filter should be done.

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REFERENCES

[1] M. R. Dhage, V. S. Girnale and C. P. Patil, "Review on Solar Photovoltaic Water Pumping System," *Int. J. Sci. Res. & Develop.*, vol. 5, no. 1, pp. 1042-1045, 2017.

[2] T. M. Bloming and D. J. Carnovale, *Application of IEEE Standards 519-1992 Harmonic Limits*, 2004. https://www.eaton.com/content/dam/eaton/products/backup-power-ups-surge-it-power-distribution/power-conditi-oners/harmonic-correction-unit/IEEE-std-519-1992-harm-onic-limits.pdf [Assess Date: 13 May 2022].

[3] P. Narale and N. S. Rathore, *Solar Water Pumping System for Agriculture*, https://5.imimg. com/data5/ RR/MK/PR/SELLER-3733354/solar-water-pump-system-with-subsidy.pdf [Assess Date: 13 May 2022].

[4] Y. Alhazmi, *Allocating Power Quality Monitors in Electrical Distribution Systems to Measure and Detect Harmonics Pollution*, MSc Thesis, University of Waterloo, 2010.

[5] A. K. Atawneh, A. M. Abualrub and R. J. shalode, *Harmonic Study for Palestine Polytechnic University Wadi-Al Haria Campus*, BTech Thesis, University of Palestine Polytechnic, 2017.

[6] *Passive Filter Design: Harmonic Filter Design Procedure*, https://www.pscad.com/software/pscad/overview [Assess Date: 13 May 2022].