Modeling and Performance Analysis of Two Different Inverter Topologies for Integration of 180 Kw Solar Photovoltaic (Spv) System to Distribution Grid at Rubesa

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Abstract
Solar photovoltaic system (SPV) is one of the clean and environment friendly renewable energy sources which is deployed by many power utilities and domestic households. The solar photovoltaic system (SPV) exhibits an intermittent nature of power source, its output power never remains constant throughout the day. Thus maximum power point tracking method is implemented to minimize the power variation. For the grid connected SPV system, grid-tied inverter is important component. The nature of output current and voltage depends on the circuit topology of inverter. Thus the behavior of PV array and inverter is analysed by modeling and simulating in MATLAB/Simulink software. Hence this paper presents on modeling and performance analysis of grid-tied sinewave and five-level multilevel inverter with fuzzy logic-based maximum power point tracking using MATLAB/Simulink software. The nature of inverter output voltage and current is analysed and compared for five different performance parameters.
Key Words : *Fuzzy logic, Maximum power point tracking (MPPT), Mebership function, Solar Photovaltic System (SPV), Simulink, Boost converter, Fuzzy set, Multilevel, Sinusoidal pulse width modulation*

1. INTRODUCTION

Every year around the world, the development of renewable energy sources in power market are slowly increasing.The change in climatic condition has added the concern over environment and drastic increase in electricity demand has forced the growth of renewable energy sector. Amoung various renewable energy sources, solar energy is considered as most clean, promising and intermittent in nature. SPV technologies has growth rate of 35-40% per year (Argyrou & Christodoulides, 2018)
As SPV system is non-linear in nature, its output power changes with the change in environmental condition, hence there is a problem associated with harnessing of maximum power from solar energy. To increase the efficiency of SPV system it is important to study the technology used for harnessing
maximum power available from the sunlight. An inverter is one of the most important component in SPV system to generate quality output voltage and current, thus performance study of grid connected inverter is crucial. Therefore, this paper presents the modeling and performance analysis of sinewave and fivelevel multilevel inverter topology with fuzzy logic based maxium power point tracking in MATLAB/Simulink software. The tracking ability of fuzzy logic-based MPPT and inverter's output voltage and current charasteristic are also analysed.
For modeling and performance analysis of SPV system with inverter, 180 kW grid connected SPV system at Rubesa is considered. For the performance of MPPT, real-time irradiance and temperature data of April month of 2019 is considered.

2. DESCRIPTION OF PV ARRAY

The PV array comprises of number of string connected in parallel and number of module conected in series to form a string. 180 kW SPV plant at Rubesa consists of three pairs of PV array, in each pair each array is rated for 31.1 kW and 28.9 kW, total of 60 kW in each. 31.1 kW PV array (five parallel string of 18 series connected module per string) is considered for study in this project.
In this study, MATLAB/Simulink library build-in PV array block was used with boost converter. Signal builder block was used to feed the input data to the PV array. The real-time data was sampled for every hours and imported to signal builder block. As voltage from the PV array is not constant throughout the day, hence DC-DC boost converter is modeled and implemented to interface PV array and inverters.

3. MODELING OF DC-DC BOOST CONVERTER

3.1 DC-DC Boost Converter

DC-DC boost converter is electronic circuit which converts variable input DC voltage to adjustable output DC voltage. The input voltage to boost converter is output voltage from PV array. DC-DC boost converter is modeled with inductor, capacitor, blocking diode and MOSFET switch. All the building block is brought from Simulink library. The value of inductor and capacitor are designed by analyzing the ripple content allowed in output voltage and current. The Fig. 1 shows the boost converter model in MATLAB/Simulink.

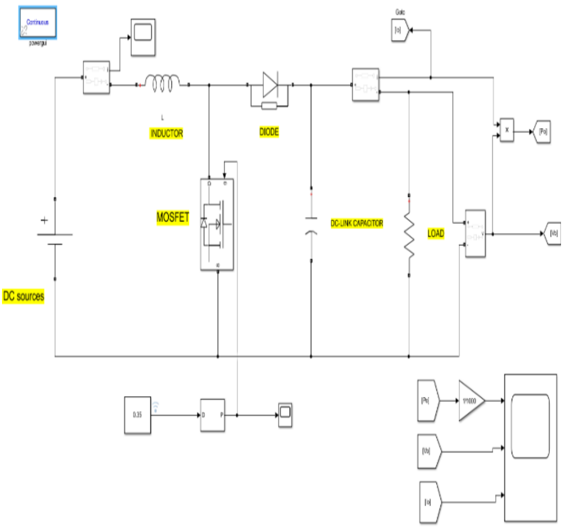

Fig. 1: *MATLAB/Simulink model of DC-DC boost converter*

Converter is able to step up variable input DC voltage from PV array. The PV array at STC (1000 W/m^2, 25°C) generates 711 V and it is stepped up to 1100 V to feed inverters. The input voltage to converter is not fixed when there is change in irradiance and temperature, thus converter steps up variable input voltage to constant DC voltage of 1100V.

The step up action of DC-DC converter is controlled by the pulse of the switch. The variable pulse to the switch is generated from the MPPT algorithm. The fuzzy logic-based MPPT algorithm is implemented in proposed SPV system to generate variable pulse to boost converter.

4. MAXIMUM POWER POINT TRACKING

4.1 Concept of Maximum Power Point Tracking

Photovoltaic (PV) cell has ability to convert 30 to 40 percent of sunlight, that is photon energy into electrical energy (Benaissa et al., 2017). The efficiency of the PV module or array can be increased by allowing the PV module or array to operate at its maximum power point. In our proposed SPV system, fuzzy logic-based MPPT is modeled and implemented using boost converter. The proposed SPV system has ability to generate 31.1 kW power at STC, thus MPPT is implemented to track required power. Fig. 2 shows the typical view of implementation of boost converter in PV array.

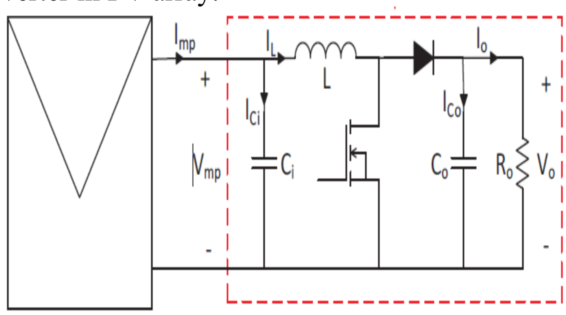

Fig. 2: *Schematic of the MPPT boost converter*

The 31.1 kW PV array is connected to boost converter and boost converter is driven by variable duty cycle generator algorithm. The variable duty cycle of MOSFET switch in boost converter will match the impedence seen by PV array and hence it transfers maximum power to connected load or invrters. Thus boost converter and fuzzy logic MPPT is modeled and studied.

4.2 Fuzzy Logic-based Maximum Power Point Tracking

Fuzzy logic controller is independent of the exact model of PV system and it has the ability to handle non-linear system (Basha & Rani, 2020). It is simple to model and easy to implement in MATLAB/Simulink software.

Fuzzy logic has three basic structure namely, fuzzification, inference engine (rule based) and defuzzification. Unlike boolean logic, fuzzy logic has ability to generate output value between 0 and 1. This property of fuzzy logic is used to generate variable duty cycle. The output of PV array, current and voltage is fed to input of fuzzy logic controller. The numerical value of input current and voltage is converted into linguistic variable by fuzzification. The inference engine evaluates the rule and defuzzification generates variable numerical duty cycle.

Based on the output power variation, the rule is set to generate output. If the power of PV array crosses peak power then reduced duty cycle is generated. And if power of PV array lies on left hand side of peak power point then rule is set to increase duty cycle. Thus this ability to generate output between 0 and 1 of fuzzy logic control is implemented to generate variable duty cycle. The input and output linguistic variable are represented by triangular function as shown in Fig. 3, 4, 5.

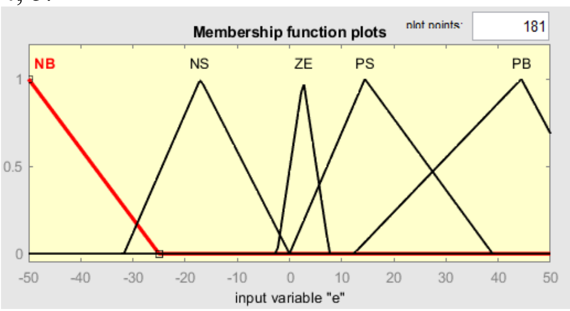

Fig. 3: *Membership function for input slope (e).*

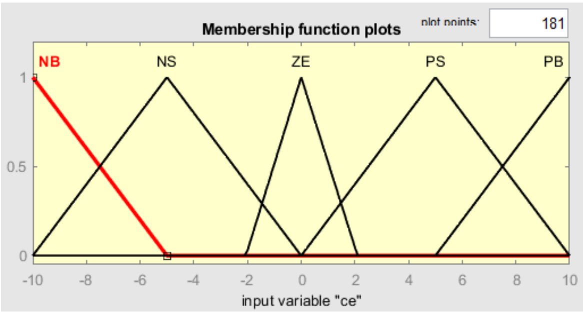

Fig. 4: *Membership function for input change in slope (Δe).*

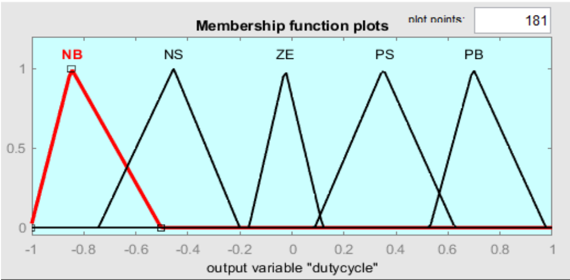

Fig. 5: *Membership function of output variable.*

5. MODELING AND PERFORMANCE ANALYSIS OF INVERTERS

In solar photovoltaic system, inverter perform the conversion of variable DC voltage from the PV array to desired magnitude of AC voltage. There are several types of inverters used in SPV system. Among many, sinewave and multilevel inverter (MI) are modeled and its performance are in studied MATLAB/Simulink software for 180 kW SPV system at Rubesa.

5.1 Five Level Multilevel Inverter (MI)

MI technology is employed for the power quality and to reduce the switching losses in the system. MI has more level of output voltage than other conventional inverter. The main idea of five-level multilevel inverter is to generate five level of output voltage per cycle that is (0.02 sec) as shown in Fig. 6. The five level of voltage are $2V_{dc}$, V_{dc}, 0, $-V_{dc}$, $-2V_{dc}$. Where V_{dc} =1100 V.

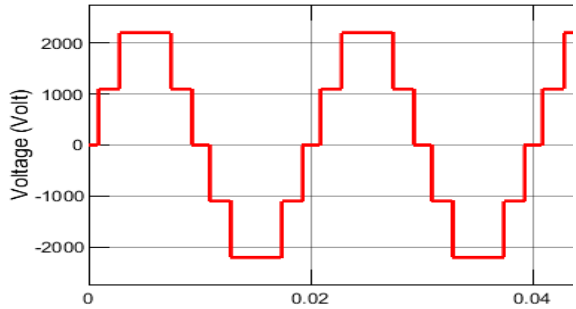

Fig. 6: *Output waveform of five-levl MI*

To generate five level of output voltage in each phase, two single-phase H-bridge inverter are connected in series. Two series H-bridge inverter are fed by two DC sources that is PV array at 1100 V. To construct single-phase H-bridge inverter, four IGBTs switch are used from simulink library with antiparallel diodes. Two switch in each arm are connected in series and fed by constant DC voltage from PV array. The working of single-phase H-bridge inverter is same as conventional single-phase inverter. The Fig. 7 shows the single-phase five-level multilevel inverter.

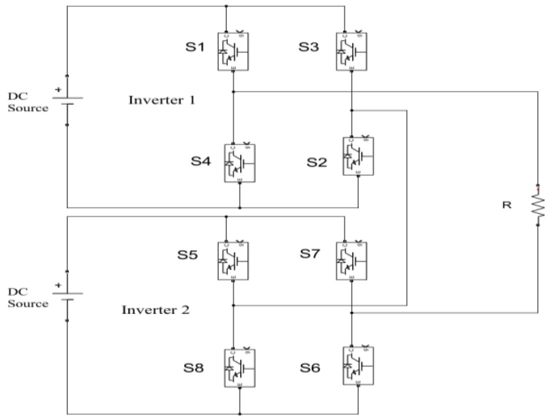

Fig. 7: *MATLAB/Simulink model of single phase fivel level MI*

To construct three-phase five-level inverter, three single-phase five level inverters are used. Each phase is displaced by 120° to generate balanced three phase voltage. In three-phase five-level multilevel inverter total twenty four IGBT switches are used and there are six input DC sources. The proposed 180 kW SPV system also consists of six PV array: Time (second) .t DC source is fed by each PV array.

a. Voltage Control of MI

To control the output voltage of inverter, sinusoidal pulse width modulation technique is implemented. In this method, sinusoidal signal of frequency 50 Hz is compared with multi-carrier triangular signal of frequency 2500 Hz. Repeating sequence block was used to generate carrier signal and sinewave block was used to generate switching pulse for the switch. Comparator block was used to compare the signal, when the sinewave signal amplitude is greater than reference signal amplitude, comparator block generate 1 otherwise 0. 1 means switch is ON and 0 mean switch is OFF. To generate three phase of 120° displaced output voltage the reference signal used for each phase of inverter is displaced by 120° respectively. The input DC voltage to the inverter is 1100 V from PV array which is the constant output voltage from DC-DC boost converter. The Fig. 8 shows carrier (blue, red, green, purple) and reference signal (yellow) implemented for voltage control of five level multilevel inverter.

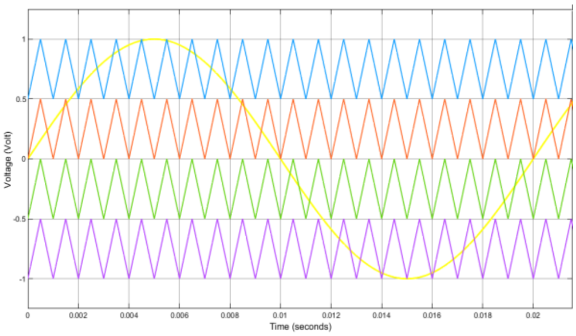

Fig. 8: *Reference and carrier signal*

5.2 Sinewave Inverter

The basic three phase sinewave inverter consists of six IGBTs and six antiparallel diodes. To achieve three phase voltage at output terminal of inverter, three arms of each with two IGBT and two antiparallel diodes are modeled using MATLAB/Simulink. 180° conduction mode voltage controlled inverter is modeled. Fig. 9 shows the Simulink model of sinewave inverter. The sinewave inverter is constructed using six IGBT switches, two in each arm. Switch is modeled with each antiparallel diode. The upper switch conducts after every 120° and the switch in each arm conducts for 180° one after another the cycle continue after one cycle that is 0.02 sec. The input to the inverter is fed from the PV array at constant voltage of 1100 V. 180 kW SPV system consists of three inverter of 60 kW each. For the simulation propose, only one inverter is considered and other two remains same. PV array of 60 kW is fed to each inverter. The output of inverter is connected to load and analysed it's performance at different load.

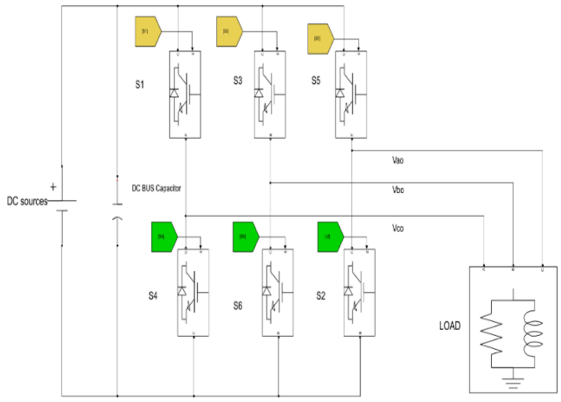

Fig. 9: *MATLAB/ Simulink model of sinewave inverter.*

a. Voltage Control of Sinewave Inverter

In proposed sinewave inverter model, the three sinewave signal of 50 Hz each displaced at 120° is compared with 2500 Hz single triangular carrier frequency signal, when the amplitude of sinewave signal is higher than carrier signal it generate output 1 otherwise 0. 1 means switch is ON and 0 mean switch is OFF. The comparator and repeating sequence block are used to generate pulse from simulink library.

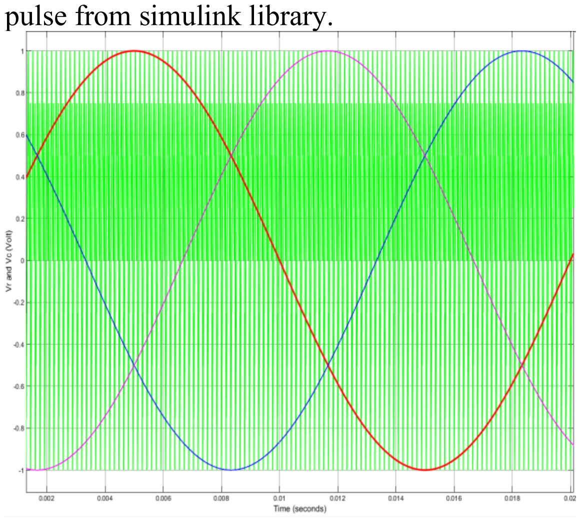

Fig. 10: *Reference and carrier signal*

5.3 Performance Parameter

In grid connected inverter, the nature of output voltage and current determines the quality of output power thus the output of two modeled inverters are compared with five different performance parameters. The performance parameter at which two inverters is compared are as follows:

1. Total harmonic distortion (THD)

2. Efficiency
3. Form factor
4. Crest factor
5. Ripple factor

Efficiency is one of the most important parameter at which inverter are selected for SPV system. Thus the efficiency of two inverters are compared at 100% and 50 % load. Other four parameters monitor the nature of output voltage and current whether it is close to pure sinusoidal waveform or not. Hence the output of two inverters are compared on this parameter.

6. RESULTS AND ANALYSIS

The boost converter is modeled and then simulated for constant input voltage of 711 V and optimal duty cycle of 0.35 to see performance of boost converter. The simulation was carried out for 5 sec and observe the output voltage, current and power from the converter. Fig. 10 reperesents simulation result of boost converter.

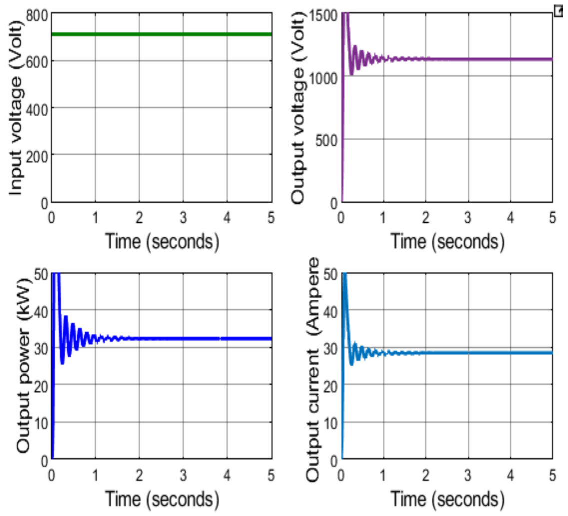

***Fig. 11:** Boost converter output voltage,current and power waveform*

From the Fig. 11, the output voltage is higher than input voltage. The input voltage is 711 V and average output voltage was 1098 V which is close to 1100 V at duty cycle 0.35. The output power found was 31.05 kW where as at STC output power is 31.1 kW hence boost converter is able to stepped up the voltage and transfers the maximum power to inverter.

The fuzzy logic-based MPPT was simulated for 0.6 sec at STC initially and later it was simulated for variable irradiance and constant temperature. The steady state response and efficiency of MPPT is analysed and studied. The Fig. 12 shows the simulation result of MPPT at STC. From the Fig. 12, the MPPT takes some times to reach steady state. At T=0.021 sec power from the PV array reached to almost rated value of 31.1 kW, but MPPT is able to track up to 30.5 kW. Similarly MPPT is able to maintain constant voltage at 711 V and average PV output current at 43 A. Modeled fuzzy MPPT is able to operate PV array at its maximum power point. This constant power is fed to inverter at constant voltage.

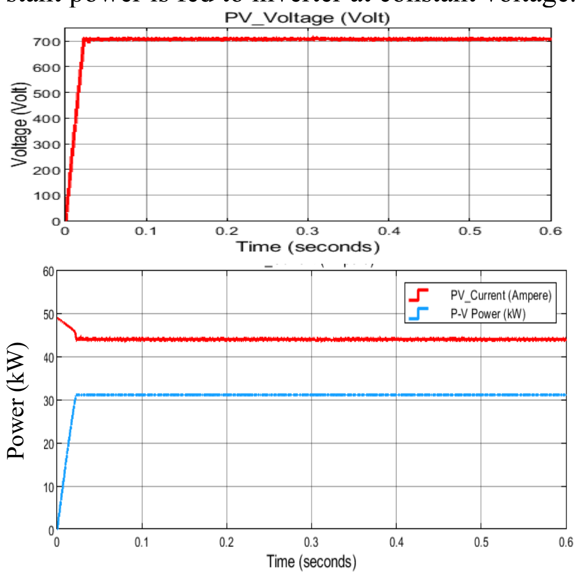

***Fig. 12:** PV array output voltage, current and power at STC.*

To check the effect of variable irradiance and costant temperature, MPPT is simulated with three different irradiance and constant temperature of 25°C. The irradiance of 1000 W/m^2, 600 W/m^2 and 400 W/m^2 is applied at interval of 0.2 sec. The Fig. 12 shows the response of MPPT at variable irradiance and constant temperature.

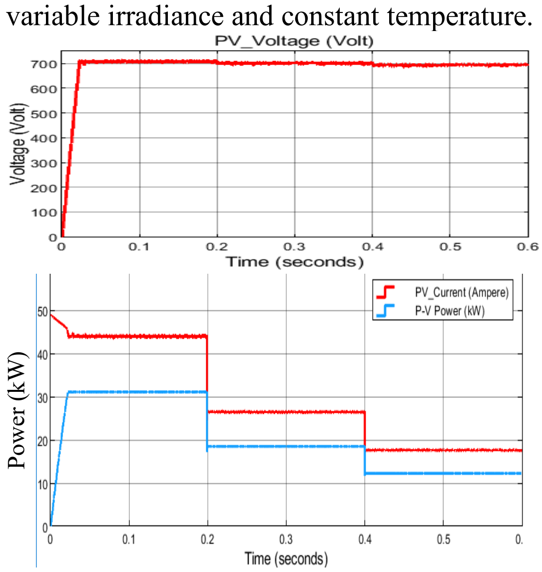

***Fig. 13:** PV array output voltage, current and power at variable irradiance.*

From the Fig. 13, when there is change in irradiance the output power and current also changes, thus MPPT is able to track the maximum power at each irradiance. The PV array output voltage remains same when there is change in irradiance. MPPT is able to track maximum power when there is sudden fall in irradiance. From the result, MPPT is able to maintain maximum power prom PV array when there is change in weather condition.

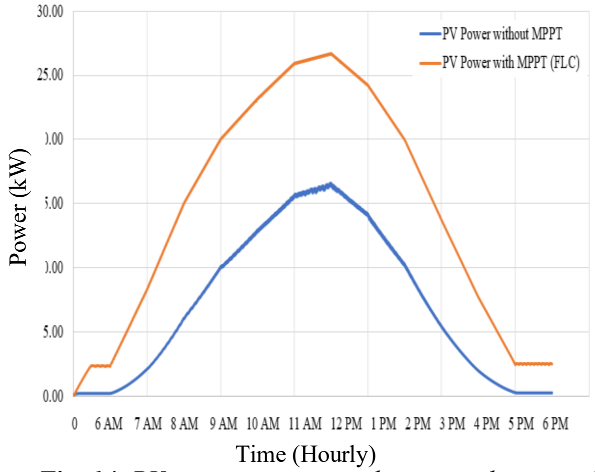

Fig. 14: *PV array power at real time irradiance and temperature data.*

Fig. 14 shows the simulation result of MPPT and without MPPT of modeled PV array and inverter. From the Fig. 14 the maximum power of 26 kW was able to extract from the available maximum power of 27.730 kW at 12:30 PM with MPPT and without MPPT only 16 kW was able to extract. The power starts to generate at 6 AM and MPPT is able to track the maximum power for each irradiance and temperature. With MPPT array operate at its maximum power point and thus it tracks all the available power from the PV array. Without MPPT power obtained at same irradiance and temperature was less as compared to with MPPT. Without MPPT the array is not able to operate at its maximum power point thus it reduces the efficiency of PV array. From the Fig. 14 it was observed that PV array with MPPT help to increase the efficiency of PV array at each irradiance and temperature.

After validation of fuzzy logic-based MPPT it is interfaced with two modeled inverters and performance of inverters were analysed. The total harmonic distortion of voltage and current waveform of two inverters are analysed using FFT analysis toolbox in MATLAB/Simulink. The crest factor, form factor and ripple factor of inverters voltage waveforms are calculated and analysed.

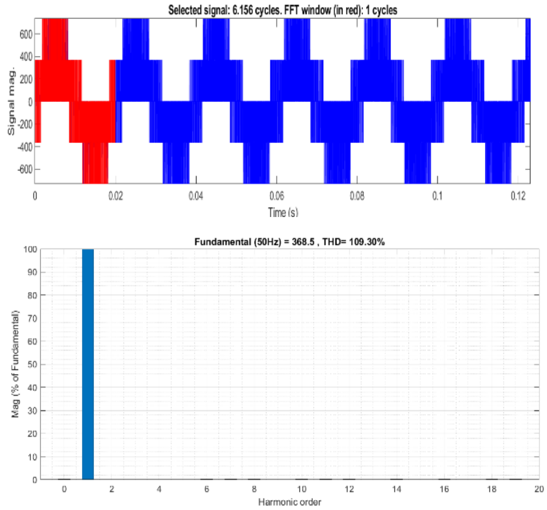

Fig. 15: *THD of sinewave inverter voltage without filter*

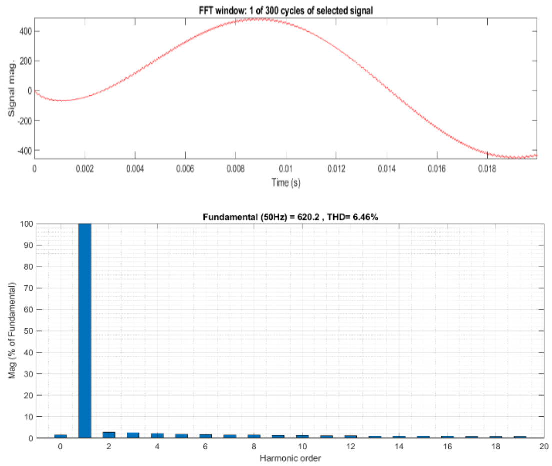

Fig. 16: *THD of sinewave inverter voltage with filter*

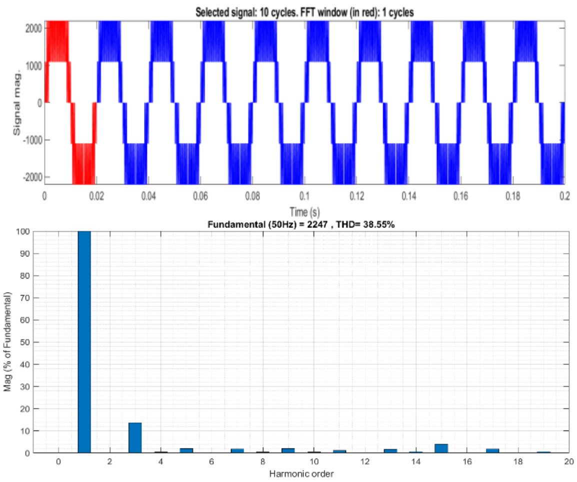

Fig. 17: *THD of five level multilevel inverter voltage without filter*

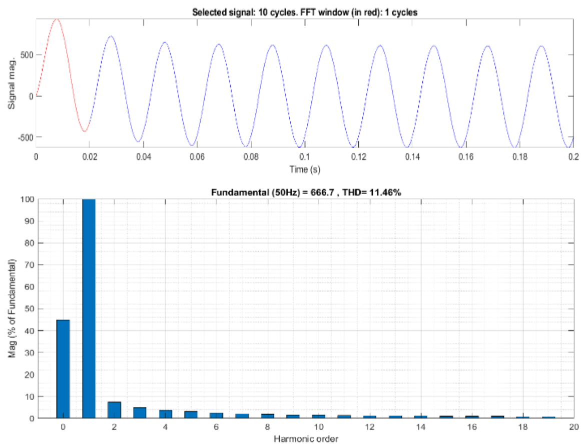

Fig. 18: *THD of five level multilevel inverter voltage with filter*

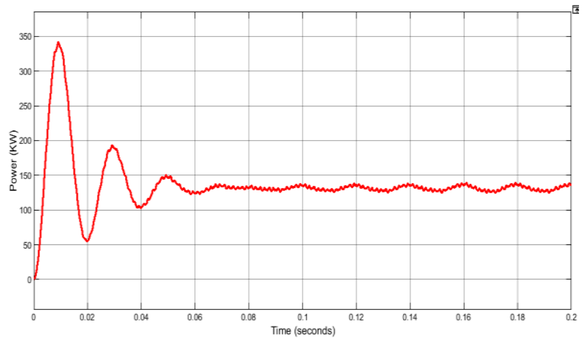

Fig. 19: *Output power of five level multi level inverter at 100% load.*

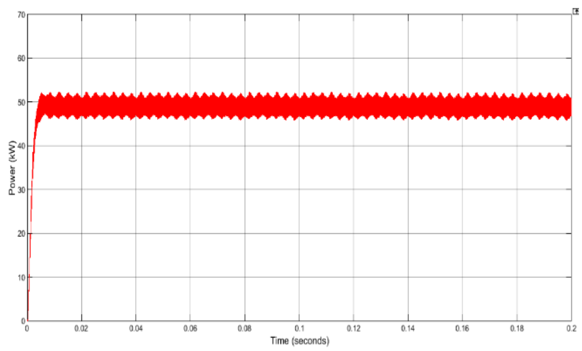

Fig. 20: *Output power of sinewae inverter at 100% load*

The table 2 presents the summary of the inverters's performance parameters. Ripple factor, form factor and crest factor is calculated from the three-phase voltage waveform of the inverters. The crest factor, form factor, and ripple factor are the parameters which measures the degree of closeness of voltage and current waveform to fundamental sinusoidal waveform. From the simulation result it is found that the sinewave inverter's output voltage and cutrrent is close to the fundamental waveform. The harmonic content in the sinewave inverter is low.

The sinewave inverter has low ripple factor, it means that the variation of inverter's output voltage from peak value is less. The efficiency of sinewave inverter is high as compared to five-level MI. From the simulation analysis the MI inverter has more number of switches hence there is more switching losses. MI inverter requires higher value of filter capacitor and inductor hence more losses is found.

7. CONCLUSION

The 180 kW SPV system at Rubesa in Wangduephodrang Dzongkhag was modeled in MATLAB/Simulink software. The model includes the SPV array each of 31.1 kW, fuzzy logic-based MPPT with boost converter and Sinewave and five-level MI topology. The MPPT is tested under STC, variable irradiance, constant temperature and variable irradiance and variable temperature.

Table 2: *Summary of the performance parameter*

Performance parameter	Five level MI		Sinewave inverter	
	With filter	**Without filter**	**With filter**	**Without filter**
THD in voltage	11.46 %	38.55%	6.40%	109.30%
THD in current	12.05 %	17.10%	4.86%	89%
Crest factor	1.536		1.478	
Form factor	2.156		1.061	
Ripple factor	1.910		0.354	
Efficiency	82.22% (at rated load) 72.22% (at 50% of rated load)		89.4% (at rated load) 87.2% (at 50% of rated load)	

The sinewave inverter is fed by 60 kW SPV array and five-level inverter is fed by 180 kW SPV array. The output characteristic of voltage and current waveform of the two inverters are compared with the performance parameters. The main conclusion from this study are as follows:

- Fuzzy logic MPPT under STC could obtain a maximum power up to 30.5 kW from the 31.1 kW PV array.
- Under variable irradiance and temperature, the efficiency of the fuzzy-logic based MPPT is found to be average of 97%. The steady state response of the MPPT is 0.021 sec
- Fuzzy logic-based MPPT has low oscillation around Maximum Power Point of Solar PV system.

- The Total Harmonic Distortion of sinewave and five-level MI inverter voltage is found to be 6.40% and 11.46% respectively with filter.
- From the simulation result the efficiency of sinewave inverter is higher than the five-level Multilevel Inverter and sinewave inverter output voltage and current is close to the fundamental sinusoidal voltage and current with minimum deviation.

Among many inverter topology sinewave inverter and five-level inverter are modeled in this project and compared its performance. After analyzing its performance as shown in table 2, this study recommends to implement sinewave inverter topology for SPV system.

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