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Multiple Roof-Top PV System's Combined with Interactive Grid

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ABSTRACT: The paper suggests a method for controlling bidirectional power flow in a grid-connected multiple solar PV system located in different places used for Residential & agricultural power requirement, for example - Water Pumping. It likely discusses how to efficiently manage power transfer between the solar array, the utility grid and the load (water pump). The system allows a user to run the water pump at maximum capability continuously for a day, in any case of the weather condition. Additionally, during times when water pumping isn't needed, the system can supply excess power back to the single-phase utility grid. This kind of flexibility can help optimize energy usage and ensure consistent power supply. The mutual power flow control between the utility and the DC bus of the VSI is managed by a 1- ϕ (VSC) voltage source converter. This converter is responsible for facilitating the energy exchange. The VSI in turn, supplies power, which is used for water pump in agricultural sector. This arrangement allows efficient control of power flow and utilization of energy. Operating the voltage source inverter at the fundamental frequency is a strategy employed to minimize switching losses. By using this approach, the system aims to reduce energy losses that occur during switching transitions of the inverter. This can contribute to overall energy efficiency and performance improvement of the bidirectional power flow control system. In this system, operation of the PV array at its MPP is achieved by optimizing the energy production from the solar panels. Additionally, power quality enhancements are implemented, including reduction of THD and PF correction of the utility grid. This improvement contributes to efficient power utilization and higher quality of energy exchange between the grid and the system. The system's applicability and reliability are showcased through simulated results of BLDC motor for water pumping, conducted on MATLAB platform.

KEYWORDS: Maximum power point (MPP), voltage source inverter (VSI), Solar photovoltaic (PV), brushless dc (BLDC) motor, total harmonic distortion (THD), power flow control, voltage source converter (VSC), power factor (PF), unite vector template (UVT), power quality, bidirectional power transfer (BPT).

I. INTRODUCTION

The rising carbon level in atmosphere and depletion of fossil fuels are strong motivation for consumer to move on with renewable energy sources. Solar photovoltaic generation is increasingly recognized as a superior alternative to conventional energy sources for various appliances [28]. The stand-alone solar photovoltaic system has many drawbacks (unavailability of power in a) bad climatic condition, b) night times) that causes shutdown of system. Attempts to resolve these drawbacks are found in [19],[9][27][15], using batteries. Batteries do solve the above-mentioned problems but also leads to higher upfront costs, increased maintenance, and reduced service life [22], [8]. Lead-Acid batteries, commonly used in such systems, typically have a useful life of around 2 to 3 years [12]. The drawbacks associated with battery storage have promoted a focus on exploring alternative technological solutions. This newly identified technologies involve integrating a PV generating unit with utility grid. This approach can offer benefits such as reduced reliance on batteries. Such an interactive system is mentioned in [25], where by eliminating the need for battery storage, overall life of system is extended, and both manufacturing and maintenance costs are minimised. But the developed mechanism allows only one-way flow of power, i.e., from utility grid to load. So, any surplus power from the PV array cannot be sent back to the utility grid. The above mentioned and many others [7], [26], [13] configurations of PV systems employ unidirectional power flow control, where system either supplies power to grid or draws power from grid.

The advancement of bidirectional power flow control is aimed at enabling two-way energy transfer is given in [16]. This permits power to flow from the photo-voltaic array to the 1- ϕ utility grid when power requirement is zero, while also allowing to draw power from grid if PV array's power is insufficient. The above-mentioned approach is reliable

and enables full utilization of PV-system, but not multifunctional in a sense that it uses a solo PV array to feed the grid. Which do offers to consumer a small earning source by transferring power to utility grid, but this earning could be manifold by combining multiple such small PV arrays (owned by private residentials) to feed the grid. This system will also manifold the capacity of PV system, power delivered to grid and reduce the installation cost by using High level VSI & VSC instead of separate devices for individual system. Certainly, using BLDC motor drive water pumping system [23] as load for example will help illustrate the application of the proposed system and its capabilities. The simplicity of the unit vector template (UVT) approach makes it effective for achieving this objective of BPT. The system aligns with the power quality standards specified in the IEEE-519 standard [6].

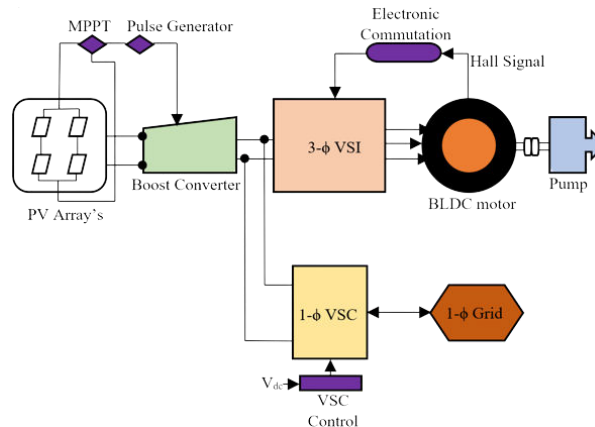


Fig. 1. Schematic of Multiple Roof-Top PV System's Combined with Interactive Grid using BLDC motor as load.

The incremental conductance (InC) technique is used with a dc-dc boost converter to achieve maximum power point tracking (MPPT) for PV array [24]-[28]. Contribution of work is given below:

- 1) System proposes the intra-connectivity among small capacity solar PV systems installed in residential area.
- 2) The proposed bidirectional power flow control enable's continuous power utilization.
- 3) The system is designed with a control mechanism that redirects power converted by PV array to utility grid when power requirement is zero. The system's ability to sell excess electricity to grid can generate additional income.
- 4) Maintaining power quality standards according to the IEEE-519, regardless of power flow direction (weather feeding power to grid or drawing from grid), is a crucial aspect of the proposed system.

II. CONFIGURATION

A brush-less dc motor driving a pump, supplied by the PV array & grid (as per requirement) is proposed in Fig.1. A BLDC motor is connected to photovoltaic array through a voltage source inverter and boost converter. The MPPT of photovoltaic array is achieved by boost converter, using an InC algorithm. Meanwhile, the VSI is in charge of electronically commutating the BLDC motor [24], [20]. An electronic commutation is carried out by 3 Hall-effect signals, which are generated by an inbuilt encoder. A 1-φ utility grid supports the direct current of the VSI. This setup enables the power to flow in both direction between the VSC and the connected system through dc bus capacitor. The photovoltaic array is designed to supply power to grid under no-load condition, otherwise the system prioritizes PV array for load. An interfacing inductor serves multiple purposes: facilitating power exchange between grid and VSC, as well as controlling and limiting harmonic current that might affect the utility grid. The inclusion of an RC ripple filter serves to mitigate and limit harmonic components in the supply voltage [16].

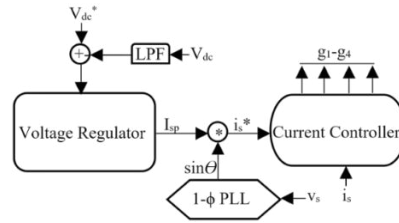


Fig. 2. Bidirectional power flow control of VSC based on Ultra Voltage Trip.

III. BIDIRECTIONAL POWER FLOW CONTROL

A bidirectional power control mechanism based on Under Voltage Trip (UVT) generation is implemented to enable power flow in both directions [14], [21], [5], shown in Fig. 2. A 1- ϕ Phase-Locked-Loop (PLL) serves the purpose of synchronizing the voltage and current of utility grid. The 1- ϕ PLL produces sinusoidal unit vector of the stock voltage, represented as $\sin(\theta)$ at the principal frequency. Also, by regulating dc bus voltage (V_{dc}) we obtain the peak value of principal components of supply current (I_{sp}). A proportional integral (PI) provides voltage regulation. The ripple component present in voltage signal is reduced by passing the V_{dc} through first order low pass filter. This filtered V_{dc} is checked side by side with a fixed value V_{dc}^* . To extract the fundamental component of the supply current (i_s^*), a product of (I_{sp}) and $\sin \theta$ is used. Now the comparison of (i_s^*) and sensed supply current (i_s) gives a difference which is processed by current controller and gate pulse of VSC is generated.

When there is a need to draw power from the grid, the voltage controller gives a positive value for amplitude of the fundamental component of supply current (I_{sp}) [16]. This avails an in-phase supply current from grid. Similarly, when power is supplied from PV array to grid, a negative value of (I_{sp}) is generated which results in out-phase supply current [16]. Likewise, by reversing the direction of current, we can effectively control the direction of power flow in a system. Certain parameters like THD and PF are managed to achieve the improved power quality at grid [16].

IV. SYSTEM DESIGN

The performance of the entire system relies on the proper coordination and control of components shown in Fig. 1 viz., PV array, BLDC motor (Load), 1- ϕ VSC, Boost converter, 3- ϕ VSI and 1- ϕ grid. So, the design of these components is given:

A. PV array

Configuration considers is the PV array capable of generating 1.5 kW electric power designed to run a load of 1.3 kW (BLDC motor pump) [16]. The standard test conditions of PV array ($1000W/m^2$, $25^\circ C$, AM 1.5) and converter and motor power losses are considered. The chosen PV module (BMU/214) has a maximum power point voltage (MPP) of 28.5 volts and MPP current of 7.5 amperes [4]. PV array's voltage is chosen in consideration of the voltage requirement of load to ensure compatibility and efficient power conversion. The values of PV array are estimated as [16]. Therefore, $V_{mpp} = v_{pv} = 200V$.

$$I_{mpp} = i_{pv} = p_{pv} / v_{pv} = 1500 / 200 = 7.5 \text{ A}$$

No. of PV modules in series are

$$N_s = V_{mpp} / V_m = 200 / 28.5 = 7$$

No. of PV modules in parallel are

$$N_p = I_{mpp} / I_m = 7.5 / 7.5 = 1$$

Where, I_m = MPP current and V_m = MPP voltage.

B. Boost Converter

Designing a boost converter involves various considerations, and one of them is estimating the value of the input inductor (L). Selecting the value of L in a manner to ensure continuous conduction mode (CCM) operation, regardless the weather condition, is a crucial aspect of design. Duty ratio D_1 according to [20].

$$D_1 = (V_{dc} - v_{pv})/V_{dc} = (270 - 200)/270 = 0.25$$

Where, V_{dc} = dc bus voltage of VSI.

Therefore,

$$L = (D_1 * v_{pv}) / (f_{sw} * \Delta I_L) = (0.25 * 200) / (10000 * (7.5 * 0.2)) = 3.3 \text{ mH}$$

Where, f_{sw} is boost converter's switching frequency and ΔI_L is ripples in current through L, $I_{mpp} = I_L$.

C. 3- ϕ VSI

BLDC motor is fed by 3- ϕ VSI. The crucial estimations in design of VSI to be considered are current, volt-ampere rating, voltage. We have $V_{dc} = 270$ volt, therefore voltage rating of IGBT switch is,

$$V_{VSI} = V_{dc} * 1.4 = 270 * 1.4 = 378 \sim 400 \text{ V.}$$

1.4 = voltage safety factor, commonly chosen to account for switching transients.

And, The IGBT switch has the current rating of,

$$I_{VSI} = I_{dc} * 1.3 = (1500/270) * 1.3 = 7.23 \sim 7.5 \text{ A.}$$

Where, 1.3 = current safety factor.

Now, VA(Volt-Amp.) rating of VSI is,

$$(VA)_{VSI} = V_{dc} * I_{VSI} = 400 * 7.5 = 3 \text{ kVA.}$$

D. Common DC-Link capacitor (C)

It is the common component between 1- ϕ VSC, boost converter and 3- ϕ VSI. It manages the second harmonic components of 1- ϕ grid voltage that appears in dc bus of 1- ϕ VSC. Therefore, according to [11].

$$C = I_{dc} / (2\omega_L \Delta V_{dc})$$

$$C = (1500/270) / (2 * (2\pi * 50) * (270 * 0.008)) = 4700 \text{ } \mu\text{F.}$$

Where, ω_L = line frequency (rad/sec); I_{dc} = dc bus average current; ΔV_{dc} = ripple in dc bus voltage.

E. 1- ϕ VSC

The bidirectional power flow is managed by 1- ϕ VSC. This ensures that switching devices can handle dc-link voltage levels present in the system without breakdown. Therefore, IGBT switch's voltage rating is estimated as,

$$V_{VSC} = 1.4 * V_{dc} = 1.4 * 270 = 378 \sim 400 \text{ V.}$$

The maximum capacity of the VSC to fed or draw current from grid is estimated as,



$$I_{s,max} = \sqrt{2}(P_{mpp}/V_s) = \sqrt{2}(1500/180) = 11.78A.$$

Where, V_s = rms value of 1- ϕ utility grid.

The IGBT switch's current rating, with safety factor = 1.3 is,

$$I_{VSC} = 1.3 * I_{s,max} = 1.3 * 11.7 = 15.3 \sim 15A.$$

Now, VA rating of VSC,

$$(VA)_{VSC} = I_{VSC} * V_{VSC} = 15 * 400 = 6 \text{ kVA}.$$

F. Interfacing Inductor (L_f)

The choice of L_f is closely tied to the allowed current ripple ΔI_{VSC} . Therefore,

$$L_f = (m * V_{dc}) / (4 * a * f_{sw} * \Delta I_{VSC})$$

$$L_f = (1 * 270) / (4 * 1.2 * 10000 * (1500/180) * 0.2)$$

$$L_f = 3.3 \text{ mH}.$$

Where, switching frequency (f_{sw}) = 10kHz; over loading factor (a) = 1.2; modulation index (m) = 1; current ripple (ΔI_{VSC}) = 20% of I_{VSC} .

G. R-C Ripple Filter

On the 1- ϕ grid side, a small R-C ripple filter is used. The high pass filter of first order is employed to reduce low frequency components produced by VSC. A ripple filter allows the fundamental frequency (lower-frequency) parts of the signal to go through with higher impedance, while offering low impedance to higher frequency (switching) component. $T_{sw} \gg R_f C_r$ satisfies above condition, where, T_{sw} = switching time; R_f = ripple filter resistance; C_r = ripple filter capacitance.

Assuming, $T_{sw} = 1/10000s$; $R_f C_r = T_{sw}/4$; $R_f = 5\Omega$. Then, according to [32] C_r is,

$$C_r = T_{sw} / (4 * R_f) = 1 / (10000 * 4 * 5) = 5 \mu F.$$

Thus, an R-C ripple filter has a series combination of 5 μ F capacitance and 5 Ω resistance.

V. RESULTS OF SIMULATION

Performing an analysis of the above-mentioned framework using simulated results in the MATLAB platform allows for a comprehensive evaluation under different operation conditions. Testing the developed framework and its control across starting, dynamic, and steady state operations is crucial to ensure its robustness and reliability. System, according to [16] involves a 4 pole, 3000rpm, 1.3kW motor pump operating at 270 V(dc) as a load. The pump is powered by a 1.5kW_p PV array under standard test conditions, along with a 1- ϕ , 180V, 50Hz utility grid. Following are the possible operating conditions demonstrated on behalf of above presented system.

A. Steady state and starting performance

The primary objective of this study is to showcase the smooth start-up of the brush-less dc motor and the consistent working of the motor pump across a range of operating conditions.

- 1) When load is supplied by only PV array: The Fig. 3(a) shows, indices of BLDC motor pump (load) and PV array. As the PV array generates its highest amount of electricity under solar radiation of 1000W/m², therefore



rated speed of BLDC motor pump is achieved i.e., 3000rpm. Under above condition PV array is been operated as stand-alone system where grid is not been utilised. Fig. 3(b) also shows different parameters such as electromagnetic torque T_e , electromotive force e_a , load torque T_L , stator current i_{sa} , speed N . The outcome indicates a smooth initial start-up and effective maintenance of a stable operational state for the motor pump.

- 2) When load is supplied by utility grid only: During night time hours this operating scenario arises when water pumping is necessary. A sinusoidal supply current with a phase aligned to the voltage and having a root mean square value of 8.3 A is being utilized. Additionally, the direct current bus voltage is held at a constant level of 270 volts, as depicted in Fig. 4(a)&(b). The grid supplies sufficient amount of power to operate motor at full capacity.
- 3) Under No-load condition: Under no-load condition the power produced by PV array is directly supplied to the 1- ϕ utility. The PV array is operating at $1000W/m^2$, indicating the maximum solar irradiance level, as depicted in Fig. 5(a)&(b). Which also presents an out of phase current waveform that indicates grid fed by PV array while reversing the power flow and constant 270-volt dc.

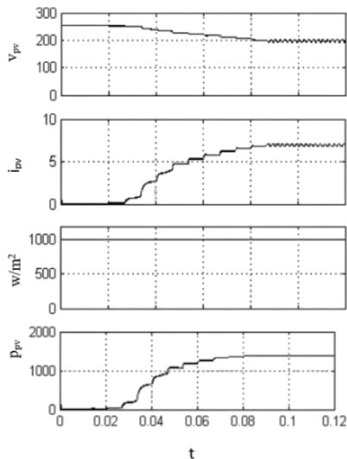


Fig. 3(a). PV array's steady state and starting performance.

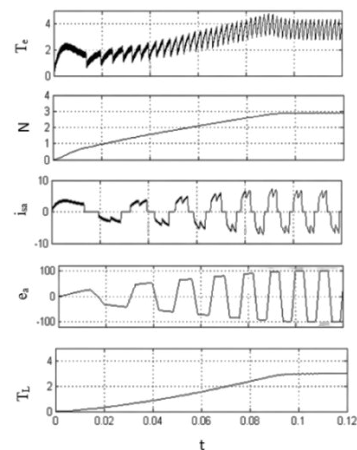


Fig. 3(b). BLDC motor at starting and steady state condition.

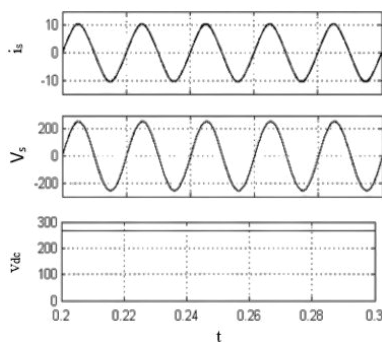


Fig. 4(a). Utility grid starting and steady state performance.

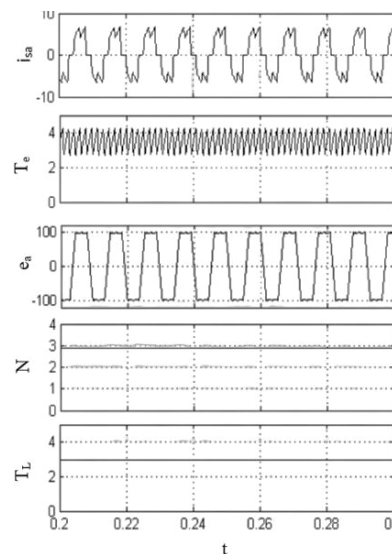


Fig. 4(b). BLDC motor at steady state and starting performance.

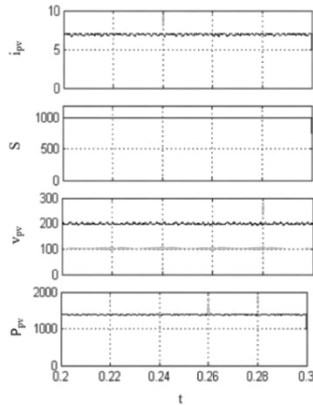


Fig. 5(a). PV array's steady state response.

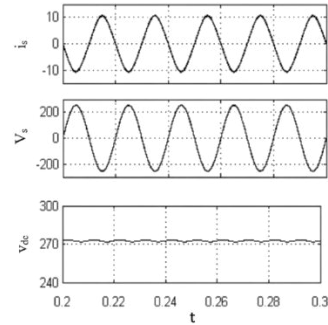


Fig. 5(b). Utility grids steady state response.

B. Changes in operating conditions

Sudden changes in climate or need for an abrupt shift in power flow directions often involve rapid adjustments to the system to maintain stability and functionality.

- 1) PV array feeding grid, when sudden No-load condition occurs: The analysis takes into account the scenario where the load is first supplied by the 1- ϕ grid, when solar PV array is not accessible. The operating mode shifts abruptly, when water pump is not operational, but solar power becomes available. So, the new objective is to supply the utility grid with the energy produced by the photovoltaic array, as depicted in Fig. 6(a), (b)&(c).
- 2) Under reduced radiation, pump draws combined power from grid and PV array: In this scenario, the assumption is that the water pump is initially powered solely by the PV array, which is capable of providing enough energy to run the pump at its maximum capacity. There is a decrease in sun's dispersion level from 1000-500 W/m^2 , and this change occurs within a span of 0.3 seconds. With the radiation level reduced to 500 W/m^2 , the PV array is unable of operating the water pump at its maximum capacity. The intention now is to supplement the power shortfall from the photovoltaic array by drawing the additional needed supply from the grid, that is shown in Fig. 7(a), (b)&(c).

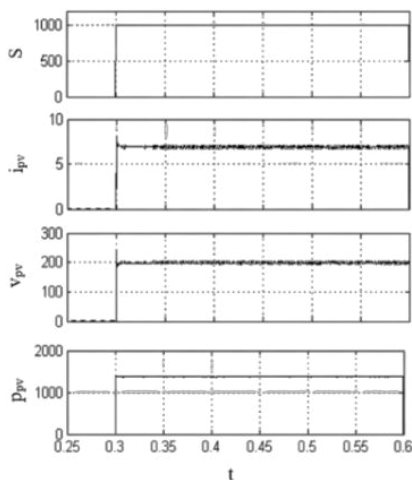


Fig. 6(a). PV array's dynamic response.

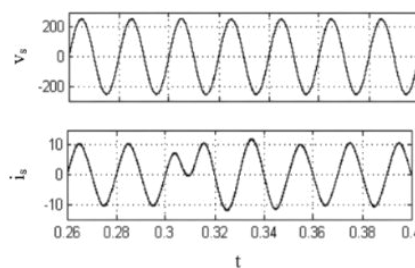


Fig. 6(b). Utility grid's dynamic response.

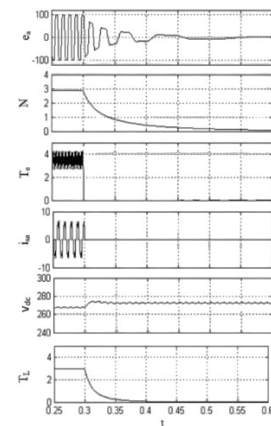


Fig. 6(c). Transition of BLDC motor. (From grid supplied to PV array supplied).

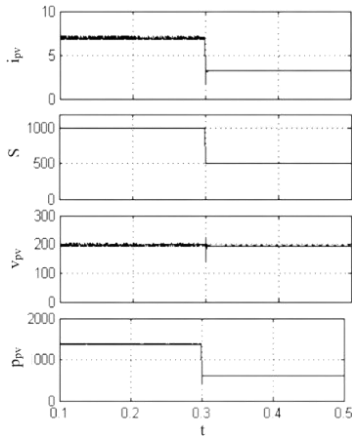


Fig. 7(a). PV array's dynamic performance.

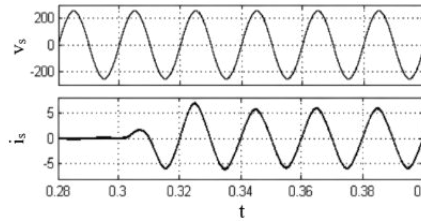


Fig. 7(b). BLDC motor's dynamic performance.

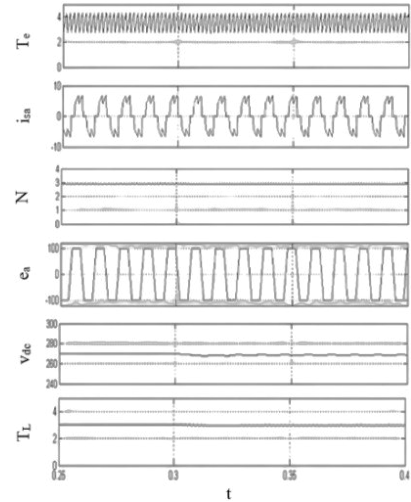


Fig. 7(c). Utility grid's dynamic performance.

C. Aspect of power quality

The suggested system offers enhancement in power quality for the utility grid. This improvement encompasses factors such as power factor and total harmonic distortions. If the water pump is solely powered by the 1- ϕ grid, the total harmonic distortion and harmonic spectrum of the supply current (i_s) will be influenced. Likewise, with 600 W/m^2 of solar radiation, additional power is sourced from the utility, the total harmonic distortion and harmonic spectrum of supply current (i_s) will be affected as shown in Fig. 8. In both scenarios, the total harmonic distortion of the i_s remains under 5%, which aligns with the IEEE-519 standard for acceptable power quality. The system guarantees a unity power factor operation across different operating conditions.

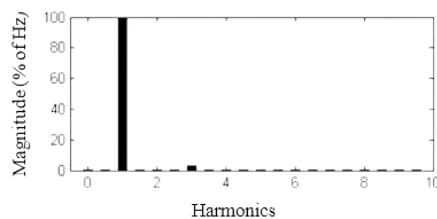


Fig. 8. Harmonic spectrum and THD of i_s when motor is fed by Grid & both PV array and grid.

VI. CONCLUSION

Bidirectional power flow control in a Voltage Source Converter allows for efficient resources utilization at maximum capacity, irrespective of climatic condition. Applying a straight forward unbalanced voltage tolerant generation technique helps achieve the desired power flow control. The power quality perspective has been successfully achieved in accordance with the IEEE-519 standard. Implementing fundamental frequency switching in the voltage source inverter has improved overall system efficiency by minimizing switching losses. The suggested solution has become a source of revenue by selling excess electricity to grid, particularly under no-load condition.

REFERENCES

- [1] X. Li, H. Wen, L. Jiang, W. Xiao, Y. Du, and C. Zhao, "An improved MPPT method for PV system with fast-converging speed and zero oscillation," *IEEE Trans. Ind. Appl.*, vol. 52, no. 6, pp. 5051–5064, Nov./Dec. 2016.
- [2] M. Metry, M. B. Shadmand, R. S. Balog, and H. Abu-Rub, "MPPT of photovoltaic systems using sensor less current-based model predictive control," *IEEE Trans. Ind. Appl.*, vol. 53, no. 2, pp. 1157–1167, Mar./Apr. 2017.

- [3] R. K. Agarwal, I. Hussain, and B. Singh, "Three-phase single-stage grid tied solar PV ECS using PLL-less fast CTF control technique," *IET Power Electron.*, vol. 10, no. 2, pp. 178–188, Feb. 2017.
- [4] Crystalline Silicon PV Modules. [Online]. Available: <https://www.platendt.nl/pdf/bisol-0906-en.pdf>
- [5] S. Premalatha, S. S. Dash, and P. C. Babu, "Power quality improvement features for a distributed generation system using shunt active power filter," *Procedia Eng.*, vol. 64, pp. 265–274, 2013.
- [6] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE Standard 519-2014, 1992.
- [7] C. Steel, A. Fang, S. Weilong, G. Jing, and Z. Xiong, "Photovoltaic agricultural power generating unit," Chinese Patent CN 203859717 U, Oct. 1, 2014.
- [8] A. Boussaibo, M. Kamta, J. Kayem, D. Toader, S. Haragus, and A. Maghet, "Characterization of photovoltaic pumping system model without battery storage by MATLAB/Simulink," in *Proc. 9th Int. Symp. Adv. Topics Elect. Eng.*, Bucharest, Romania, 2015, pp. 774–780.
- [9] A. Khiareddine, C. B. Salah, and M. F. Mimouni, "Power management of a photovoltaic/battery pumping system in agricultural experiment station," *Solar Energy*, vol. 112, pp. 319–338, Feb. 2015.
- [10] A. Thangavelu, S. Vairakannu, and D. Parvathyshankar, "Linear open circuit voltage-variable step-size-incremental conductance strategy-based hybrid MPPT controller for remote power applications," *IET Power Electron.*, vol. 10, no. 11, pp. 1363–1376, Sep. 2017.
- [11] B. Singh, V. Bist, A. Chandra, and K. Al-Haddad, "Power factor correction in bridgeless-Luo converter-fed BLDC motor drive," *IEEE Trans. Ind. Appl.*, vol. 51, no. 2, pp. 1179–1188, Mar./Apr. 2015.
- [12] Z. Yan, "Photovoltaic pumping system using power grid as energy storage device," Chinese Patent CN 202455296 U, Sep. 26, 2012.
- [13] R. Kumar and B. Singh, "Grid interfaced solar PV based water pumping using brushless dc motor drive," in *Proc. IEEE Int. Conf. Power Electron., Drives Energy Syst.*, Trivandrum, India, 2016, pp. 1–6.
- [14] R. Kumar and B. Singh, "Grid interactive solar PV based water pumping using BLDC motor drive," in *Proc. IEEE 7th Power India Int. Conf.*, Bikaner, India, 2016, pp. 1–6.
- [15] A. Khiareddine, C. Ben Salah, and M. F. Mimouni, "Strategy of energy control in PVP/battery water pumping system," in *Proc. Int. Conf. Green Energy, Sfax, Tunisia*, 2014, pp. 49–54.
- [16] R. Kumar and B. Singh, "Grid Interactive Solar PV-Based Water Pumping Using BLDC Motor Drive" in *IEEE Transactions on Industry Applications*, vol. 55, no. 5, september/october 2019.
- [17] R. Kumar and B. Singh, "Grid Interactive Solar PV-Based Water Pumping Using BLDC Motor Drive" in *IEEE Transactions on Industry Applications*, vol. 55, no. 5, september/october 2019.
- [18] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications and Design*, 3rd ed. New Delhi, India: Wiley, 2010.
- [19] K. Rahrah, D. Rekioua, T. Rekioua, and S. Bacha, "Photovoltaic pumping system in Bejaia climate with battery storage," *Int. J. Hydrogen Energy*, vol. 40, no. 39, pp. 13665–13675, Oct.
- [20] V. Bist and B. Singh, "Reduced sensor configuration of a power factor correction based single-ended primary inductance converter fed brushless dc motor drive," *IET Power Electron.*, vol. 8, no. 9, pp. 1606–1615, Sep. 2015.
- [21] N. Patnaik and A. K. Panda, "Comparative analysis on a shunt active power filter with different control strategies for composite loads," in *Proc. IEEE Region 10 Conf.*, Bangkok, Thailand, 2014, pp. 1–6.
- [22] J. H. Ugale and M. S. Panse, "Single phase ac drive for isolated solar photovoltaic water pumping system," in *Proc. Int. Conf. Green Comput. Internet Things*, Noida, India, 2015, pp. 1285–1287.
- [23] A. El Khateb, N. A. Rahim, J. Selvaraj, and M. N. Uddin, "Fuzzylogic-controller-based SEPIC converter for maximum power point tracking," *IEEE Trans. Ind. Appl.*, vol. 50, no. 4, pp. 2349–2358, Jul./Aug. 2014.
- [24] R. Kumar and B. Singh, "BLDC motor driven solar PV array fed water pumping system employing zeta converter," *IEEE Trans. Ind. Appl.*, vol. 52, no. 3, pp. 2315–2322, May/June. 2016.
- [25] Huang, "Photovoltaic water pumping and residual electricity gridconnected system," Chinese Patent CN 204131142 U, Jan. 28, 2015.
- [26] L. T. Qiang, "Solar power station with water pumping and energy storage," Chinese Patent CN 103595337 A, Feb. 19, 2014.
- [27] S. G. Sigarchian, A. Malmquist, and T. Fransson, "Modeling and control strategy of a hybrid PV/wind/engine/battery system to provide electricity and drinkable water for remote applications," *Energy Procedia*, vol. 57, pp. 1401–1410, 2014.
- [28] M. T. A. Khan, G. Norris, R. Chattopadhyay, I. Husain, and S. Bhattacharya, "Auto inspection and permitting with a PV utility interface (PUI) for residential plug-and-play solar photovoltaic unit," *IEEE Trans. Ind. Appl.*, vol. 53, no. 2, pp. 1337–1346, Mar./Apr. 2017.



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