Analyzing solar PV System at Loading Points while subjecting it to AI Based Control

Prem Kumar Das[1] and Jyoti Bansal[2]

[1]Prem Kumar Das, ME, IES College of Technology, Bhopal (M.P.), India
[2]Jyoti Bansal, Asst. Professor, IES College of Technology, Bhopal (M.P.), India
premeeecit@gmail.com

* Corresponding Author: Prem Kumar Das

Abstract: *With growing concern for the environment and rising energy prices, more and more renewable energy sources are being integrated into the electricity grid in the form of decentralized generation (DG) or decentralized energy resources. The main objective of this study is to make the system more efficient in managing DC loads at local level and, after switching to three-phase current, to improve the voltage and voltage currently available on the line. Improve PV system output power by using more reliable and accurate MPPT algorithm than P&O algorithm. This work proposed an algorithm based on the global maximum power point tracking method and uses an optimization technique that follows wolf behavior monitoring criteria and works with variable illumination photovoltaic systems. The quality study on the AC side showed an improvement in the harmonic level of the voltage and waveform of the current. The% THD in the voltage and current waveforms was 8.63% and 9.35%, respectively, with a suggested optimization algorithm based on the gray wolf being 10.52% and 13.66% in the algorithm based on P&O.*

Keywords: *THD, PV, DG, microgrid*.

I. Introduction

With growing concern for the environment and rising energy prices, more and more renewable energy sources are being integrated into the electricity grid in the form of decentralized generation (DG) or decentralized energy resources (DER). Instead of using fossil fuels, energy storage devices such as batteries or ultracapacitors combined with an electronic power converter system provide a quick response to frequency control and load changes. Recent developments in battery technology offer numerous benefits such as high performance, longer overall life and high charging and discharging efficiency. For microgrids to function reliably, the system must be able to supply power to island loads while maintaining appropriate voltage and frequency levels within acceptable harmonic limits.

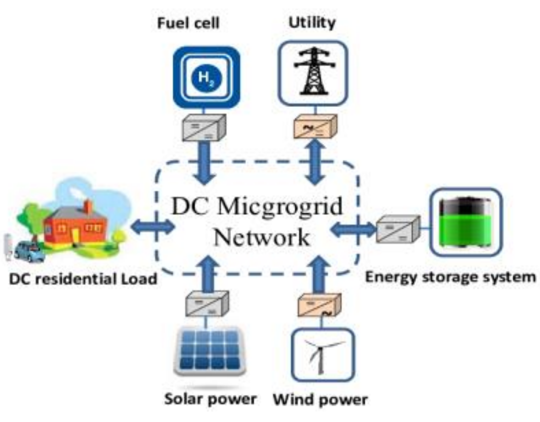

Fig. 1 The Structure of a residential DC microgrid

II. Literature Review

AdamHirsch et al. [1] This article introduces micro-networks that are moving from laboratory benches and pilot demonstration sites to commercial markets, fueled by technological improvements, cost reductions, proven track record and growing recognition of their benefits. They are used to improve the reliability and resilience of power grids, manage the addition of decentralized clean energy resources such as wind and photovoltaic (PV) to reduce fossil fuel emissions and provide electricity in areas that are not supported by a centralized electrical infrastructure. . This review article (1) explains what a micro-grid is and (2) provides a multidisciplinary portrait of today's micro-grid pilots, real-world applications, challenges and future prospects.

FuratDawood et al. [2] This article presents self-sustaining microgrid systems based on 100% renewable energy that can be developed through robust energy storage systems to stabilize variable and intermittent renewable energy resources. Hydrogen as an energy carrier and energy storage device has gained tremendous interest around the world in recent years. The proposed hybrid energy systems have been shown to have significant potential to electrify remote communities with low energy production costs, as well as to help reduce their carbon footprint and alleviate the energy crisis in order to achieve a sustainable future.

G. BaliramIngale et al. [3] This paper provides modeling of photovoltaic (PV) panels and the design of a maximum power point (MPPT) control algorithm for a photovoltaic-based autonomous decentralized generation (DG) system. A detailed mathematical model of the photovoltaic module is provided. One of the most classic MPPT (Perturb and Observe MPPT) is used to track the maximum power point of the system. SunPower solar panels are taken into account and simulation results show module properties and panel properties. A detailed design technique is provided for the MPPT technique and simulations are performed with different solar irradiations.

H. Lan et al. [4] Studies show that improper placement and size of energy storage devices (ESS) lead to unwanted power losses and the risk of voltage stability, particularly with high penetration of renewable energy. To solve the problem, a micro-grid based on the IEEE 34 bus distribution system is implemented in this article, which consists of a wind power generation system, a photovoltaic generation system, a diesel generation system and a storage system of energy in relation to various types of loads.

III. Objective

The work focuses on following main objectives:

- To design an algorithm that can be faster to track the global maximum power point. So, the tracking efficiency is improved.
- To make the system more efficient in dealing with DC loads at local level and after conversion to three phase AC the voltage and current available at the line should be improved.
- To enhance the power output from the PV system by using MPPT algorithm that is more reliable and accurate that P & O algorithm.
- To make the system responsive towards varying irradiation level in the environment and get regulated uninterrupted output from the system.

IV. Methodology

A PV energy conversion system consists of a PV module, a dc-dc device, an electrical converter, and ideally an energy storage system (ESS). The PV module is established by PV cells that are series and parallel connected to generate the specified rated power. In the system under study, the output of DC sources are connected to DC/DC boost converter and the dc link voltage is regulated. The function of DC link controller is to track the voltage across the capacitor, compare it with the reference value, and process the error value in such a way that steady state error is zero.

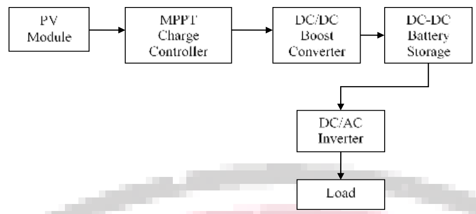

Fig. 2 Basic architecture of a PV system

Figure 2 shows the Simulink diagram of the island's solar battery system. TATA Power solar system with 10 modules in series and 3 strings in parallel. Figure 4.2 shows the simple scheme of the solar system and its connection to independent domestic loads with converter with battery on DC load, parallel to single-phase inverter on AC load.

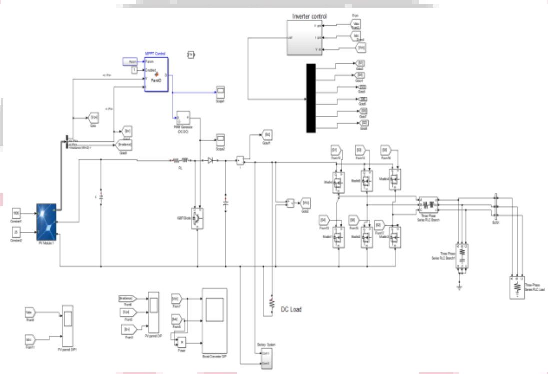

Fig. 3 Complete Simulink diagram of the proposed system

The operation of a single PV cell can be explained by an equivalent electrical diagram, as shown in Figure 3. Photovoltaic cells have a single operating point at which the current (I) and voltage (V) values of the cell give maximum power. These values correspond to a certain resistance which is equal to V / I. A simple equivalent circuit diagram of a PV cell is shown in Fig. 3.
The MPPT algorithm was used to obtain continuous operation of the solar module at maximum power.

A cell series resistor (Rs) is connected in series with a parallel combination of cell photocurrent (Iph), exponential diode (D) and shunt resistor (Rsh), Ipv and Vpv are cell current and current respectively of cell. It can be expressed as,

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$

Where:

I_{ph}- Solar-induced current

I_S - Diode saturation current

q - Electron charge (l.6e^{-l9}C)

K - Boltzmann constant (l.38e^{-23}J/K)

n - Ideality factor (l~2)

T - Temperature ^{0}K

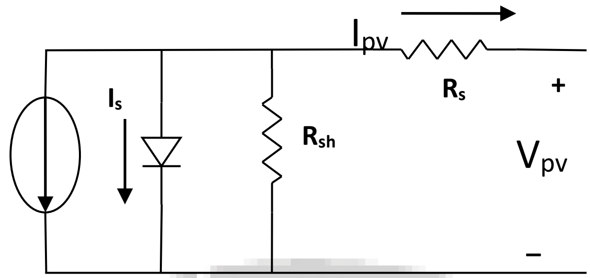

Fig. 4 Equivalent circuit of solar pv cell

The solar induced current of the solar PV cell depends on the solar irradiation level and the working temperature can be expressed as:

$$I_{ph} = I_{sc} - k_i(T_c - T_r) * \frac{I_r}{1000}$$

Where:

I_{SC}Short-circuit current of cell at STC

k_iCell short-circuit current/temperature coefficient(A/K)

I_r Irradiance in w/m^2

T_C ,T_r Cell working and reference temperature at STC

A PV cell has an exponential relationship between current and voltage and the maximum power point (MPP) occurs at the curve of the curve, as shown in Figure 4.4.

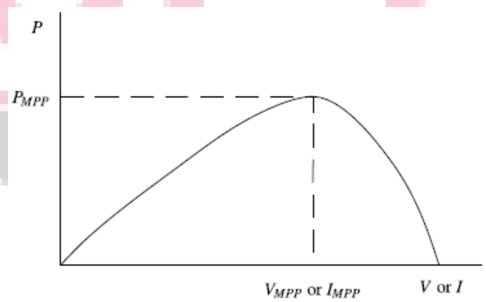

Fig. 5 Characteristic PV array power curve

The MPPT algorithm tracks the maximum power to power the DCMG system. The assumptions for the derivation of the model are that the ideal energy source can be represented by the behavior of the PVs. Furthermore, all converters operate in continuous conduction mode (CCM) and harmonics are also ignored.

Battery Storage systems.

The battery can switch from charge to discharge mode to maintain balanced DC link performance. When the energy storage device reaches its capacity limit, it maintains the power balance of the DC link by exchanging energy to / from the AC grid.

Table 1: Battery modeling parameters	
Nominal voltage (V)	120
Rated capacity (Ah)	200
Initial state-of-charge (%)	70
Battery response time (s)	0.01

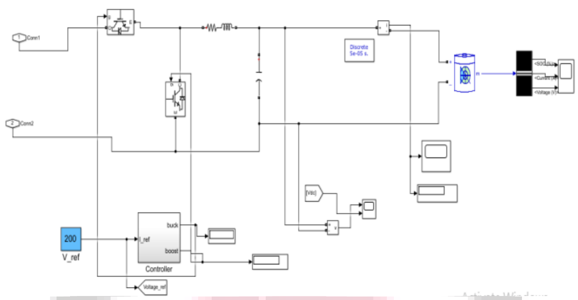

Fig. 6 Modeled Lithium-ion battery storage system

Battery storage performs charging and discharging with the difference between Ppv and PLoad. When Ppv is greater than PLoad, the energy is charged to overcome the storage unit. When the battery is fully charged, the battery control unit stops the charging process and the excess electricity generated from this point is fed into the AC grid. In battery modeling, Ibat and Vbat can be expressed as in (3) and (4) when the power consumption is P watts.

$$I_{bat} = \frac{V_{ocv} - \sqrt{V_{ocv}^2 - 4R_{bat}^{int}P}}{2R_{bat}^{int}}$$

$$I_{bat} = V_{ocv} - R_{bat}^{int} I_{bat}$$

Where;

$$V_{ocv} = f_1(SOC)$$

$$R_{bat}^{int} = \begin{cases} R_{ch} = f_2(SOC) - charging \\ R_{dls} = f_3(SOC) - discharging \end{cases}$$

$$I_{pv} = I_{ph} - I_s\left(e^{q(V_{pv}+I_{pv}*R_s)/nKT} - 1\right) - (V_{pv} + I_{pv} * R_s)/R_{sh}$$

$$SOC = SOC_{in} - \int \frac{\eta I_{bat}}{Q} dt$$

$$\eta = \begin{cases} \eta_{ch} = \dfrac{V_{ocv}}{V_{ocv} - I_{bat}R_{ch}} - charging \\ \eta_{ch} = \dfrac{V_{ocv} - I_{bat}R_{ch}}{V_{ocv}} - discharging \end{cases}$$

The battery control system was shown in the figure. The mechanism uses two PI controllers to provide signals for its charge and discharge. Controller gain is assumed to be Kp= 2, Ki= 120.

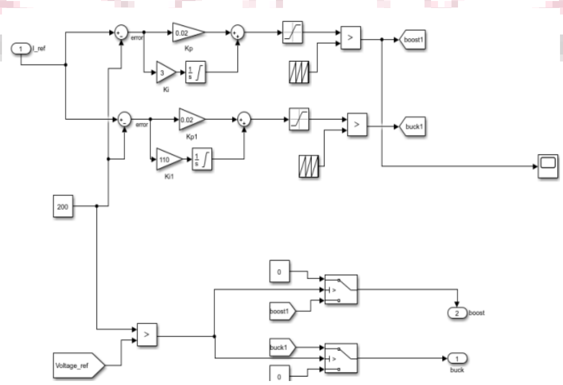

Fig. 7 Electrolyte battery controller

MPPT Design

Maximum power point tracking (MPPT) is a technique used to derive the current maximum power from a photovoltaic system. The maximum power varies according to the solar radiation, the ambient temperature and the temperature of the solar cells. The power obtained by the solar system depends mainly on geographic conditions, including the temperature and solar radiation available in selected locations. MPPT tries to achieve maximum performance based on the characteristics of the solar panels.

The maximum power depends on the availability of radiation and temperature. The MPPT algorithm is implemented on the DC-DC converter, e.g. B. on buck, boost and buck-boost converters. A boost converter is used in this project and the duty cycle of the converter is controlled by the MPPT algorithm. The general PV module with MPPT system can be used as shown in Fig.8

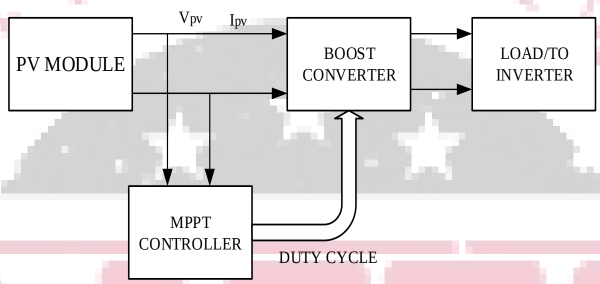

Fig. 8 Block diagram of MPPT

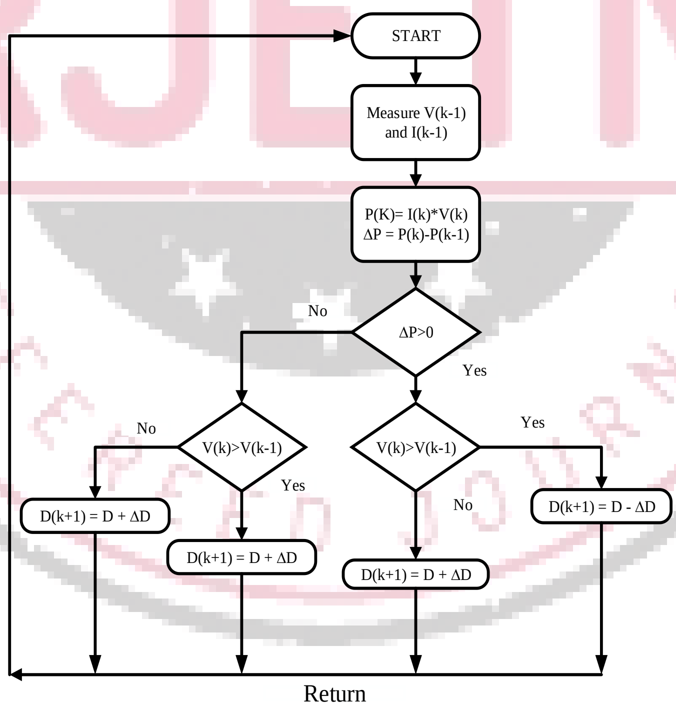

Fig. 9 Flow chart for Perturb and Observe (P&O) scheme.

There are several algorithms to extract the maximum power from photovoltaic panels, such as: B. Noise and observation (P&O), incremental conductance (IC) and fuzzy based MPPT. The choice of the appropriate technique depends on the goal of the problem, MPPT techniques depend on the application or areas of application.

Perturb & Observe is one of the most used MPPT schemes due to its simple and economical implementation. Usually this technique is used for low power applications such as B. for residential and commercial applications. In this method, the current duty point is determined based on the different voltage and power values, i.e.H. the current power and voltage value is compared with the previous values. By simply changing the duty cycle, the duty point is moved in the direction of the MPP. Flow chart for disturbance and observation in Fig. 4.8.

The main objective is to obtain the maximum output power P of the PV generator taking into account the duty cycle d as a decision variable. The objective function isformulated as follows

Maximize: P(d)

Subjected: $d_{min} \leq d \leq d_{max}$

Whered_{min} and d_{max} are limits of duty ratio.

Initialization

Initialize population Np (wolves) in search space 0.1 ≤ di ≤ 0.9 between minimum limit, 0.1 and maximum limit, 0.5 of duty ratio using (25):

d_i = rand (N_p , 1) (d_{max}- d_{min}) + d_{min}…….(25)

In this case, Np is taken as four i.e., number of modules in the PV system.

Evaluate the position of the prey

Calculate fitness values i.e., PV power of the population. Assign dα and dβ as first and second best population with highest PV power.

Updating the positions of search agents

The positions of the population di are updated according to positions of dα and dβ.

$\vec{D}_\alpha = |\vec{C}_1 . \overrightarrow{d_\alpha} - \overrightarrow{d_1}|$

$\vec{D}_\beta = |\vec{C}2 . \overrightarrow{d_\beta} - \overrightarrow{d_1}|$

$\vec{d}_1 = \overrightarrow{d_\alpha} - \overrightarrow{A_1}(\overrightarrow{D_\alpha})$

$\vec{d}_2 = \overrightarrow{d_\beta} - \overrightarrow{A_2}\,(\overrightarrow{D_\beta})$

$\vec{d}i\,(t+1) = \frac{\vec{d}1 + \vec{d}2}{2}$

where Dα and Dβ are distance of dα and dβ from maximum power.

The PV powers are calculated for updated positions of population and finish hunt when prey stops moving i.e., when maximum PV power is obtained.

Termination criterion

The algorithms terminates when it reaches maximum number of iterations and outputs dα as the optimal duty ratio to operate at maximum power.

Reinitialize

The algorithm reinitializes search for a change in solar irradiation using

$$\frac{|P_{pv}-P_{pv,old}|}{P_{pv,old}} \geq \Delta P$$

wherePpv,old is power at MPP of last operating point, ΔP is set to 10%.

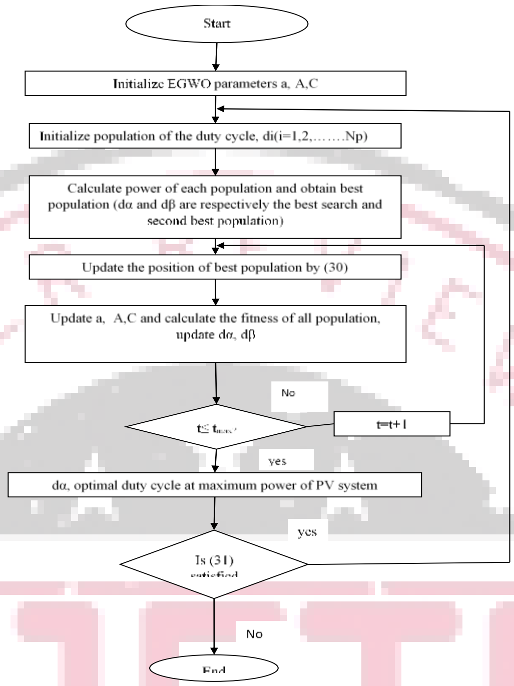

Fig. 10 Flow chart for GWO MPPT Algorithm for power optimization

DC-AC Converter/Inverter Modeling

An inverter is an electrical device that converts direct voltage into alternating voltage. In small inverters, devices such as rooftop solar panels, small micro-grids, home inverters, etc. are widespread. Two types of inverters are used, e.g. B. single-phase and three-phase inverters. A three-phase inverter has three arms with two switches each, each of which operates at an electrical angle of 180 °. The internal model of a three-phase inverter is shown in Fig.4.10. The three phase inverter is equipped with Sine Wave Pulse Width Modulation (SPWM) and has been designed and simulated. The inverter control design depends on various parameters such as DC voltage, grid voltage, grid current, switching frequency, etc. Inverter control is complemented by a combination of two-stage pulse width modulated regulators. The grid voltage is measured by the unit of measurement of the voltage and this unit of measurement is placed on the connection bus of the inverter. After removing the harmonics, the voltage and current are measured. A stage wave, which is one or two stage depending on the operating mode of 180 ° and 120 °, is converted into a pure sine wave. The proposed system is analyzed for linear and non-linear AC loads. Figure 4.10 shows the AC voltage and current for a 3 kW linear load with constant solar radiation.

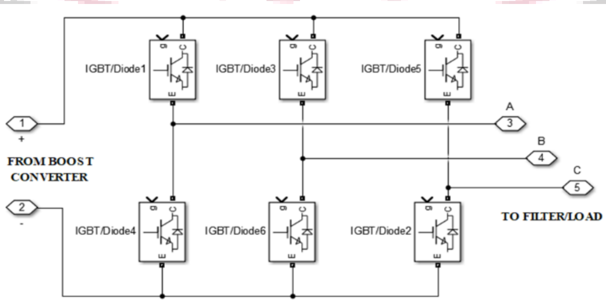

Fig. 11 Circuit diagram of three phase inverter.

V. Simulation And Result Analysis

In this research paper, the MATLAB platform is used to show the implementation or performance simulation of the implemented algorithm. The simulation results and the performance comparison of the implemented model with some existing models are calculated by the MATLAB functions.

This photovoltaic solar system operates in variable irradiation conditions. The simulation results are presented to illustrate the operating principle, feasibility and reliability of the system. The temperature is kept constant at 250 °C, the irradiation variable between 0 and 5 seconds. The system was analyzed in the following three cases:

Case1: DC output from PV system analysis modeled with two MPPT techniques

Case2: DC output from PV system analysis modeled with two MPPT techniques driving various AC loads in standalone mode.

The system was exposed to an inverter producing three-phase active output power that could also drive three-phase loads. This is because the power generated by the photovoltaic generator depends on irradiation, temperature and electrical charges, and has an MPP at a certain point of operation. The three-phase power outputs were fed to the load, which is modeled as a resistive load.

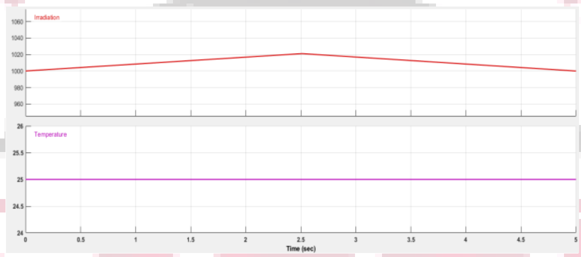

Fig. 12 Temperature and irradiation fed to the solar module

Case1: DC output from PV system analysis modeled with two MPPT techniques

In this case the results of the MPPT algorithms were analyzed. The quality of the waveforms of the two algorithms implemented to follow the maximum power is examined during the entire run time.

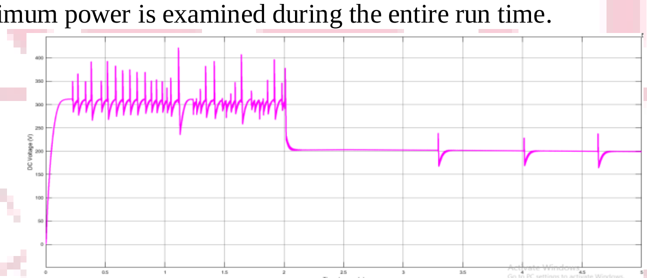

Fig. 13 DC voltage output from the system having P and O based power tracking mechanism

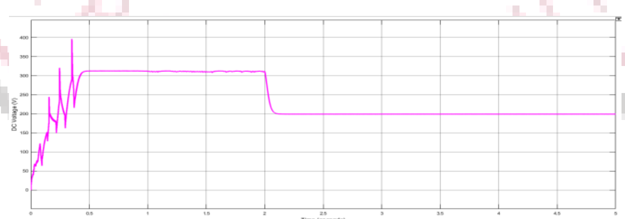

Fig. 14 DC voltage output in the system with proposed wolf optimizing based power tracking mechanism

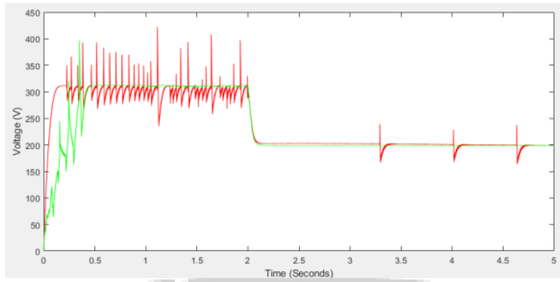

Fig. 15 Comparative voltage waveforms analysis using two power tracking algorithms

The output waveform of the green voltage is that of the optimization-based performance monitoring mechanism proposed by Wolf and has been designed to be more stable than that of the red waveform derived from an autonomous tracking algorithm system conventional based on P&O. It also affects the quality of the waveform once the inverter is converted to AC power.

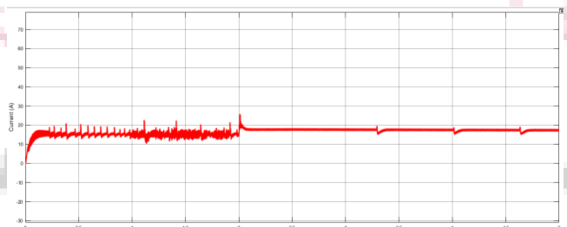

Fig. 16 DC current output from the system having P and O based power tracking mechanism

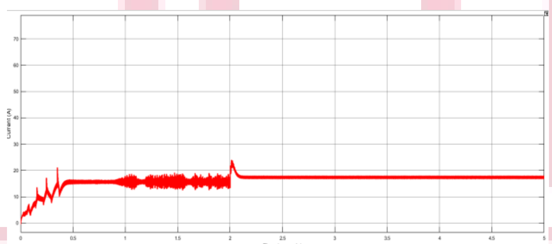

Fig. 17 DC current output in the system with proposed wolf optimizing based power tracking mechanism

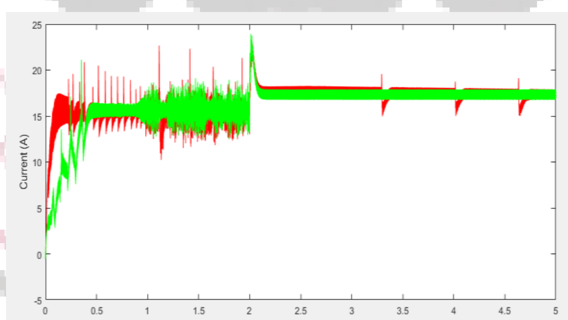

Fig. 18Comparative current waveforms analysis using two power tracking algorithms

The green waveform is a DC output of Wolf's proposed optimization-based performance monitoring mechanism and has been designed to be more stable than that of the red waveform derived from a conventional P&O-based autonomous monitoring algorithm. It also affects the quality of the current waveform after converting the inverter to AC power.

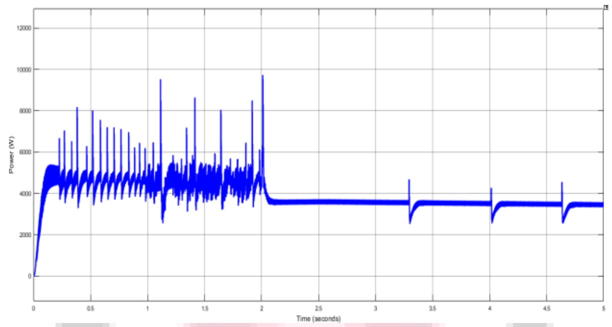

Fig. 19DC power output from the system having P and O based power tracking mechanism

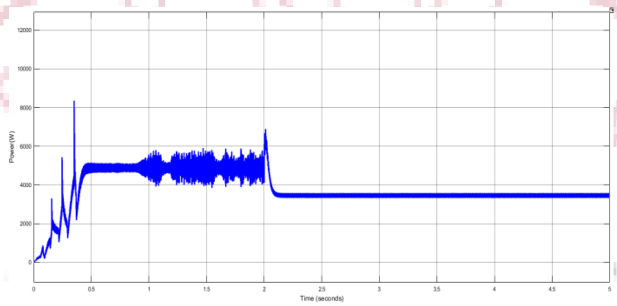

Fig. 20DC power output in the system with proposed wolf optimizing based power tracking mechanism

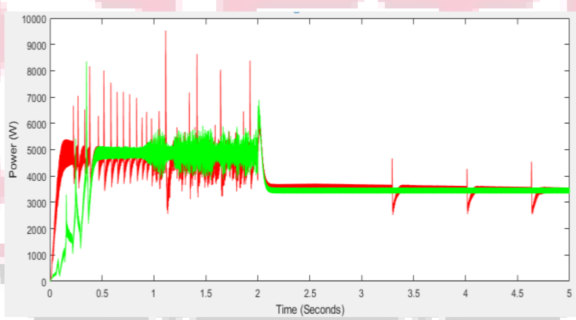

Fig. 21Comparative DC power output waveforms analysis using two power tracking algorithms

The green waveform of the output power is derived from the proposed power tracking mechanism based on Wolf's optimization and has been designed to be more stable than that of the red waveform of traditional P&O based tracking in an autonomous system , and therefore the algorithm turned out to be more efficient.

Case2: DC output from PV system analysis modeled with two MPPT techniques driving various AC loads in standalone mode. The two algorithms implemented for the MPP are further explored when converted to a three phase AC output via a converter and examining the quality available on the AC load side to justify the improvement on the DC side if changes occur as well.

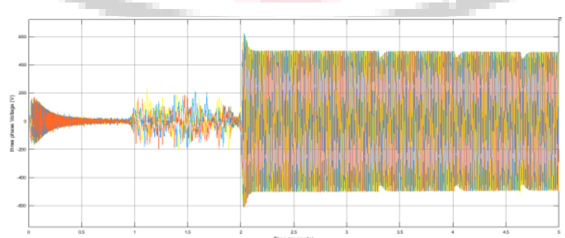

Fig. 22Three phase AC voltage in the system with P and O based power tracking mechanism

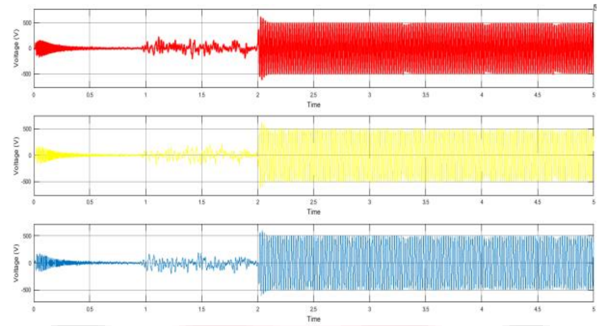

Fig. 23Per phase indication of AC voltage in the system with P and O based power tracking mechanism

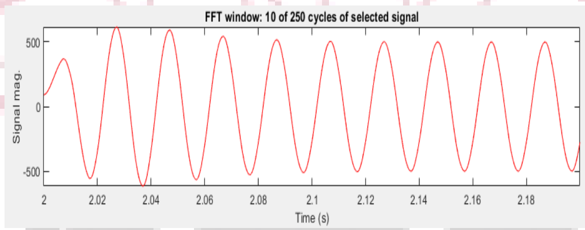

Fig. 24FFT analysis of Three phase AC voltage in the system with P and O based power tracking mechanism

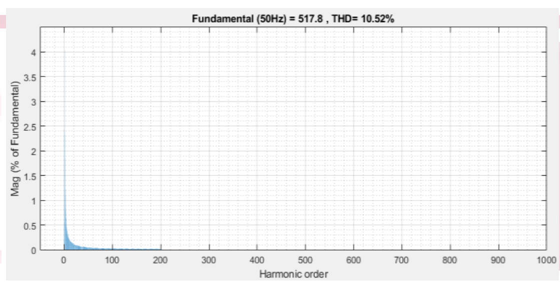

Fig. 25THD% in three phase AC voltage in the system with P and O based power tracking mechanism

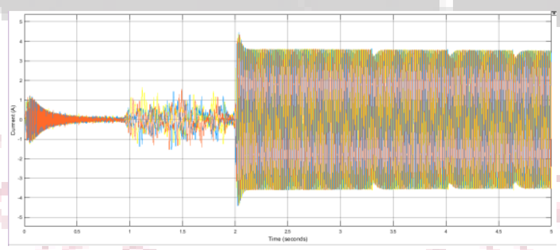

Fig. 26Three phase AC current in the system with P and O based power tracking mechanism

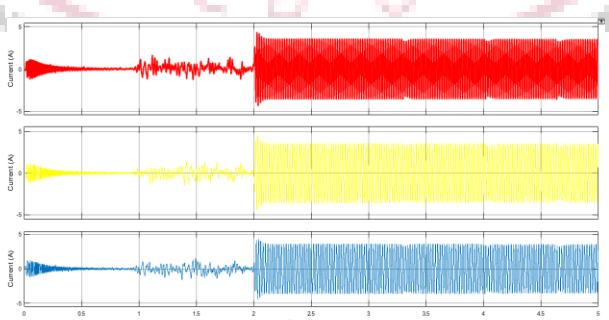

Fig. 27Per phase indication of AC current in the system with P and O based power tracking mechanism

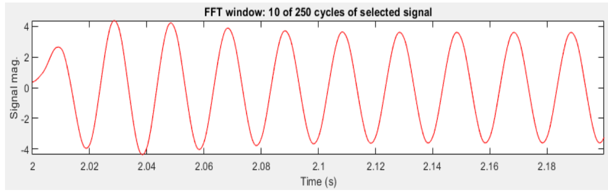

Fig. 28FFT analysis of three phase AC current in the system with P and O based power tracking mechanism

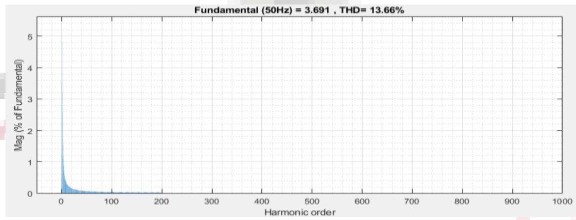

Fig. 29 THD% in three phase AC current in the system with P and O based power tracking mechanism

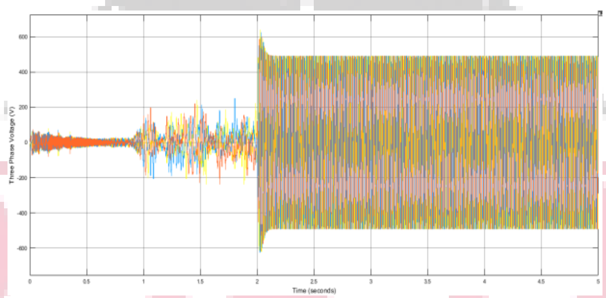

Fig. 30 Three phase AC voltage in the system with proposed wolf optimizing based power tracking mechanism

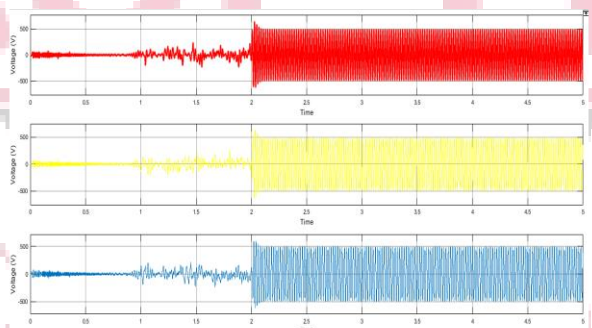

Fig. 31Per phase indication of AC voltage in the system with proposed wolf optimizing based power tracking mechanism

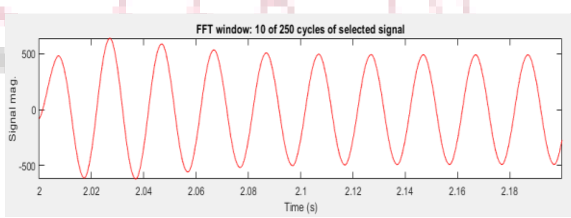

Fig. 32FFT analysis of three phase AC voltage in the system with proposed wolf optimizing based power tracking mechanism

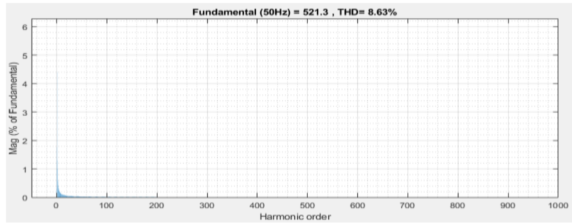

Fig. 33THD% in three phase AC voltage in the system with proposed wolf optimizing based power tracking mechanism

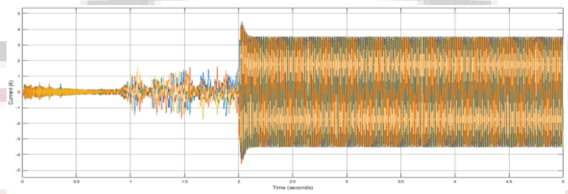

Fig. 34Three phase AC current in the system with proposed wolf optimizing based power tracking mechanism

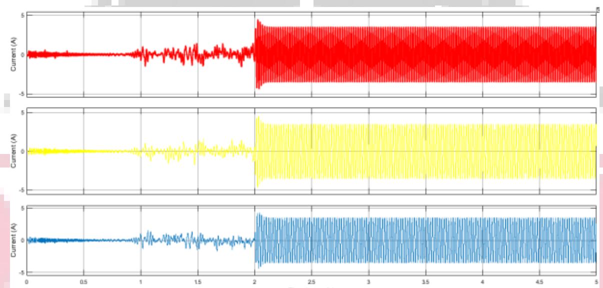

Fig. 35Per phase indication of AC current in the system with proposed wolf optimizing based power tracking mechanism

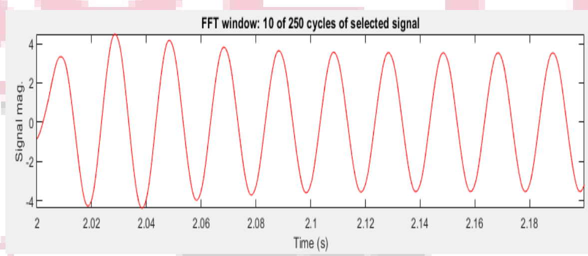

Fig. 36FFT analysis of three phase AC voltage in the system with proposed wolf optimizing based power tracking mechanism

AC and voltage waveforms are analyzed for quality I in terms of percentage of total harmonic distortion THD. The waveforms have improved at the DC load points as examined in Case 1. Improving the input from the inverter will probably also provide a better result on the AC side than the P&O algorithm, as the system is analyzed in stand-alone mode alone without network integration. The analysis is performed after the voltage stabilization in both cases.

Table 2: Quality analysis at the AC side

Systems/Parameters	Voltage THD%	Current THD%
Standalone system with P& O based tracking	10.52%	13.66%
Standalone system with grey wolf optimizer based tracking	8.63%	9.35 %

VI. Conclusion

The amount of electricity a solar system generates in a given place depends on the amount of solar energy it receives and the size of the system itself. The main advantage of a grid connected PV system is its simplicity, relatively low operating and maintenance costs.

In this thesis an algorithm has been proposed, based on the method of monitoring the point of overall maximum performance and using an optimization technique that follows the criteria for monitoring wolf behavior and works with photovoltaic systems with variable lighting.

This algorithm can be faster to keep track of the overall maximum power point. Therefore, the tracking efficiency is improved. The simulation results show that the proposed tracking control methods based on gray wolf optimization have better tracking accuracy. This thesis provides a comprehensive design and implementation of three-phase converters, as well as the control of three-phase AC loads to allow analysis on the AC side and in stand-alone mode.

Analyzing the system in the MATLAB / SIMULINK environment, the following main conclusions were drawn.

- This algorithm can be faster to keep track of the overall maximum power point. Therefore, the tracking efficiency is improved. The simulation results show that adaptive reference coordination control methods have better tracking accuracy. It also improves the energy efficiency of the photovoltaic generator.
- The output power with the adaptive reference algorithm to the DC load connection becomes more stable and uniform if it is plotted against the power result of the P&O based algorithm.
- The AC side quality study showed an improvement in the harmonic level of the voltage and current waveform. The THD% in the voltage and current waveform was 8.63% and 9.35% respectively, with the suggested optimization algorithm based on Grauwolf being 10.52% and 13.66% in the algorithm based on P&O.
- Therefore, the system with the proposed MPPT optimization algorithm has better efficiency and reliability than the P&O algorithm.

VII. Future Scope

The work can be extended to the hybrid system so that the controller is redesigned to account for changes in both solar gain and wind system input. The controller must also adapt to changes in wind speed variation. The hysteresis loop must also adapt to changes in current output due to changes in wind speed, as well as changes in lighting and inlet temperature. Hysteresis controller technology can therefore become more efficient and reliable.

References

[1] AdamHirsch, YaelParag "Microgrids: A review of technologies, key drivers, and outstanding issues", Renewable and Sustainable Energy Reviews Volume 90, July 2018, Pages 402-411.

[2] FuratDawood, GM Shafiullah "Stand-Alone Microgrid with 100% Renewable Energy: A Case Study with Hybrid Solar PV-Battery-Hydrogen", Sustainability, 6 March 2020.

[3] G. BaliramIngale, SubhransuPadhee "Design of standalone PV system for DC-micro grid", Conference: 2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS), April 2016.

[4] H. Lan, S. Wen "Modeling Analysis and Improvement of Power Loss in Microgrid", Modeling Analysis and Improvement of Power Loss in Microgrid, Volume 2015.

[5] Salman Hajiaghasi, Ahmad Salemnia "Hybrid energy storage system for microgrids applications: A review", Journal of Energy Storage, Volume 21, February 2019, Pages 543-570

[6] Y. V. pavankumar, Ravikumarbhimasingu "Renewable energy based microgrid system sizing and energy management for green buildings", Journal of Modern Power Systems and Clean Energy volume 3, pages1–13(2015).

[7] SaritaSamal, prakashkumar"Design and analysis of solar PV-fuel cell and wind energy based microgrid system for power quality improvement", 07 Nov 2017,

[8] Ahmadi, R., &Ferdowsi, M. (2014). "Improving the performance of a line regulating converter in a converter-dominated DC microgrid system". IEEE Transactions on Smart Grid, 5(5), 2553–2563. 10.1109/TSG.2014.2319267.

[9] Noroozian, R., Abedi, M., Gharehpetian, G. B., &Bayat, A. (2010). “On-grid and off-grid operation of multi-input single-output DC/DC converter based fuel cell generation system. In Electrical Engineering (ICEE)”, 2010 18th Iranian Conference on, 753–758. 10.1109/IRANIANCEE.2010.5506975.

[10] Bhim Singh, FarheenChishti “Improved Power Quality at PCC of Standalone Wind-Battery Microgrid Using Improved Normalized Sign Regressor Adaptive Control”, Proceedings of the National Power Systems Conference (NPSC) - 2018, December 14-16, NIT Tiruchirappalli, India