A Review on the Estimate Solar PV Cell Variables for Efficient Photovoltaic Systems

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Abstract- Now a days all are aware that conventional sources such as coal, petrol, diesel, nuclear are currently deteriorating day by day. Research is therefore concentrating on renewable sources such as solar, wind, tidal, biomass, etc., as an alternative to conventional sources. In all of these renewable sources, solar energy is affordable and incredibly efficient because of its cheap cost and pollution free. Therefore, regardless of their motivation, everyone chooses solar energy to meet their daily needs. As a result, to produce electricity more efficiently, the ratings of solar PV cell must take into account which panels have a significant role in determining the performance of the solar panel as well as which is also used in the construction of solar panels. And at the same time, the performance of a photovoltaic (PV) system can be obtained by estimating the accurate solar PV cell variables such as diode saturation current (Id), photocurrent (Iphoto), ideality factor (α), shunt resistance (Rsh), series resistance (Rse). All these five parameters are estimated by using the Single Diode Model (SDM) and it demonstrates the deficits in the quasi-neutral region. Researchers used a lot of methods to find out these parameters. But in this context, these parameters can be extracted by considering the series and shunt resistances.

Keywords: PV cell, Parameter Extraction, PV cell modelling, Single Diode Model (SDM)

1. Introduction

Solar energy: a brief introduction Coal, nuclear power, and fossil fuels (diesel and gasoline) are gradually being phased out as a source of energy. For the causes mentioned below. Solar photovoltaic panels (PVs) do no environmental harm since they produce no emissions during operation.[1]

(ii) Solar PV systems mitigate climate change, whereas fossil fuel-powered power plants worsen the situation.

(iii) Unlike generators that run on fossil fuels, solar photovoltaics may be found almost anywhere and in plenty.

(iv) Solar PVs have lower operational and maintenance costs. The power density of solar PV systems is the greatest of any renewable energy source.

As a result, there has been widespread interest in switching to renewable energy sources including solar, wind, tidal, and biomass to make up for this. Because of its efficiency, low cost, pollution-free, noiseless, adjustable sizes, and low maintenance requirements, solar is the most recommended usage among all of these renewable energy sources[2]. Due to the incredibly good asset mentioned above, solar PVs are quickly gaining popularity as a renewable energy source. Nearly one hundred countries worldwide rely heavily on solar panels for renewable energy. To encourage investment in renewable energy generation, governments offer financial incentives. In 2014, the world's PV power implementation was 177 GW, and by the end of 2015, that number is expected to climb to 220 GW. In 2006, electrical output was over forty times that figure [3].

Surface installations, rooftop installations, patio installations, and building-integrated PV systems (BIPVs) are all viable options for mounting solar photovoltaic panels to generate electricity for a home or business. Solar photovoltaic (PV) technology is flexible enough to be used by both big, centralized power plants and smaller, decentralized energy stations [4]. The vast bulk of solar power comes from decentralized photovoltaic energy installations. PV systems that are wired into the public power grid are referred to as grid-connected PV (GCPV) systems.

In contrast, grid-connected PV systems are unrestricted in their operation [5].

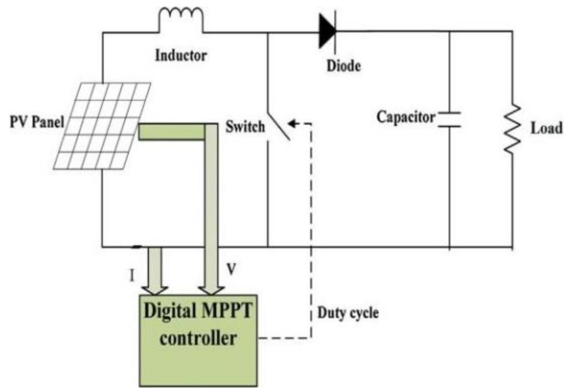

Fig.1. Illustration of a general PV system [6].

However, precisely predicting the characteristics of solar cells is necessary to get the efficient performance of solar PV systems. Research into photovoltaics, such as the impacts of sympathetic blending, on-grid and off-grid PV power plants, maximum power point tracking, and enthalpy, requires accurate modeling and calculation of photovoltaic cells. Parameter extraction for solar PV systems was the subject of much study in the preceding year. After studying the structure of PV cells, experts may advise on how to represent these cells accurately. Similarly, the formulae used to figure out these values are derived from the geometry of a sculpted photovoltaic cell. In an electrical model, the PV cell is typically represented by a series of diodes, either a single diode (SDM), a pair of diodes (DDM), or even a trio of diodes (TDM)[7]. Where the Single Diode Model (SDM) may be used to calculate all five variables and show where there are problems in the so-called neutral zone. Similar to how the Double Diode Model (DDM) is used to estimate seven variables and show losses in space-charge, quasi-neutral zones, the Three Diode Model (TDM) shows losses in all three regions and is used to estimate nine parameters. However, just five PV cell characteristics are calculated using SDM here since SDM estimation is straightforward in comparison to DDM and TDM[8-10]. However, unlike DDM and TDM, its electrical equivalent diagram is straightforward.

This study introduces a novel method for calculating the power output of an illuminated solar cell using a single diode lumped circuit model while taking into account series and shunt resistances. The conventional I 14 f(V) function is recast as V 14 f(I) and the factors C0, C1, and C2 of this function are determined to enable the computation of the illuminated solar cell characteristics. Saturation current (Is), series resistance (Rs), ideality factor (n), shunt conductance (Gsh 14 1/Rsh), and photocurrent (Iph) are typical examples of such variables [11-12]. Using the current technique, we were able to derive parameter values from the measured I-V characteristics of commercial solar cells and modules. In contrast to previous approaches, the one presented below does not require any prior knowledge of the parameters and appears to be accurate even in the presence of noise and/or random mistakes during measurement [13].

The DC characteristics of solar cells are extracted using single-diode and double-diode model-based mathematical methodologies, which are described and discussed in length in this work. The photocurrent Iph, the reverse diode saturation current Io, the diode ideality factor n, the series resistance RS, and the shunt resistance RSh are the primary parameters of importance. In this study, we take a look at the current state of parameter extraction approaches for PV solar cells and discuss their most pressing problems [14-15]. This study groups the assessed models into categories according to the amount of retrieved parameters and offers detailed feedback on each one. In order to illustrate the behavior and features of these parameters, we characterize five parameters from distinct models that have the same qualities with regard to irradiance and temperature. In addition, the performance of the PV parameters for both the single-diode and double-diode models, as well as their impact on the current-voltage (I-V) and power-voltage (P-V) characteristics, are analyzed in detail. This study also analyzes the I-V and P-V curves under standard test condition (STC) and for various parameters for a generic PV panel in order to evaluate the correctness of each model in relation to the data given by the manufacturer [16] .

The impacts of irradiance and temperature must be accounted for when determining the value of the model parameters if the PV module is to be modeled effectively. This research provides a better modeling strategy based on the differential evolution (DE) method, in light of the significance of the problem. This method of PV modeling is unique in that it allows model parameters to be computed at every irradiance and temperature point using data from the manufacturer's datasheet alone. The capacity of DE to calculate all model parameters at once under varying irradiance and temperature is the key to this enhancement. Three PV modules are tested, one each of the multi-crystalline, mono-crystalline, and thin-film varieties, to ensure the suggested model is accurate. The model's performance is measured against that of the standard single-diode model, which assumes a series resistance of Rs. The suggested model has been shown to perform exceptionally well across a wide range of irradiance and temperature conditions. This modeling approach might be helpful for those working on PV simulators who need a detailed and realistic representation of the PV module [16].

Modeling solar photovoltaic (PV) cells with sufficient precision improves the efficiency of the PV system. Incorrect solar cell parameters, however, lead to erroneous PV cell modeling. This makes it critical to efficiently get the PV cell parameters. This article's major goal is to introduce a novel stochastic optimization approach for calculating the parameters of solar PV cells. While many methods for optimization are mentioned in the literature, most of them still generate sub-optimal outcomes because they converge to local minima. As a result, this paper introduces a novel approach for solar cell estimate called the Slime Mould approach (SMA). Estimated findings are compared with experimental data to verify the performance of the proposed SMA method. Extensive statistical study demonstrates the SMA algorithm's superiority. The effectiveness of the suggested method is measured against that of other standard meta-heuristics [17] .

Parameters, metaheuristic algorithms have recently received a lot of interest. Inspired by honey bees' sophisticated foraging and nectar-processing habits, a new algorithm called artificial bee swarm optimization (ABSO) has been developed. For a commercial silicon solar cell (R.T.C. France, 57 mm in diameter), we offer a method of parameter identification using ABSO based on the single and double diode models. ABSO algorithm outperforms the other approaches investigated, and its findings are quite encouraging [18-20].

Several characteristics must be gathered from a solar panel in order to evaluate its performance. Metaheuristic algorithms are the most widely utilized of the several approaches devised to extract photovoltaic parameters from the current-voltage (I-V) characteristic curve. The purpose of this research was to report the errors that were made while identifying solar cell parameters using metaheuristic techniques. The results of this work were published in the journal Energy Conversion and Management. The results reported by the various writers fall short of the mark. The results are verified using an algorithm, and a straightforward tool, the General Algebraic Modeling System, is proposed to help extract the optimal values for the photovoltaic cell's characteristics [21].

Parameters for several types of solar cells are extracted using the pattern search optimization method presented in this research. Single-diode, double-diode, and photovoltaic modules are the variants in question. Multi-variate non-linear optimization is used to frame the estimate of solar cell characteristics. As there is no direct general analytical solution, the proposed method is utilized to solve a transcendental function that controls the current-voltage relationship of a solar cell. The accuracy with which various parameters of various solar cell types may be estimated was tested and validated across several scenarios. To demonstrate the superiority of the devised method, a comparison is shown between several parameter estimate strategies. Additionally, statistical and error studies are performed to evaluate the precision of the estimated parameters and the viability of the model [22].

In order to fit experimental data into the model of a solar cell, an optimization approach is required due to the nonlinear nature of the current versus voltage (I-V) properties of photovoltaics. The model's electrical parameters have been estimated with the help of several optimization methods. However, additional research is required to enhance model estimate. Recently, swarm intelligence-based optimization algorithms like the Firefly algorithm have been presented and have proven effective in practice. If used independently, this algorithm is effective in exploring solutions, but it requires a local optimization technique to maximize exploitation [23]. In this research, we integrate the local optimization technique of pattern search with Using the firefly method, we can enhance this one. Single and double diode solar cell models have their parameters estimated using the suggested technique. The results are compared to those of other optimization techniques for photovoltaic parameters to demonstrate the effectiveness of this approach. The outcomes demonstrate that the suggested method is a viable option for solar cell system simulation [24].

This article presents a novel method for predicting solar cell and PV module characteristics through the pattern search optimization methodology. The ideality factor, series resistance, shunt resistance, produced photocurrent, and saturation current are all estimated. To direct the estimate method to the correct model parameters, a novel objective function formulation is presented. Multiple test scenarios, including a solar cell and a PV module, are used to demonstrate the efficacy of the suggested method. To evaluate the efficacy of the created method, it is compared with the results obtained by using alternative parameter estimating strategies [25].

In this paper, we introduce a novel three-diode equivalent circuit model for large area (154.8 cm2) industrial silicon solar cells, where the parameters are lumped together. Particle Swarm Optimization (PSO) estimates of the ideality factors n1 (>1) and n2 (>2) for the two-diode model of the industrial samples do not agree with the theoretical values (n1 = 1 and n2 = 2 in the literature). The current components of solar cells cannot be precisely defined by the two diodes of the two-diode model. To better explain the experimental findings, a three-diode model has been presented. The suggested model takes into account the fact that the solar cell's series resistance, Rs, changes in response to the current that is supplied to it [26].

Photovoltaics are only efficient at converting a small fraction of the solar energy that hits them into usable electricity. Most energy loss is lost as heat, which in turn causes temperatures to rise and has a negative effect on the efficiency of solar systems. Therefore, the significance of loss mechanisms in solar cells in the solar-electric conversion process is crucial. This publication takes a comprehensive look into solar cells' internal and external losses. Parameterized energy distributions of solar cells are shown to characterize the many types of losses that can occur. The external radiative efficiency, solid angle of absorption, and operating temperature are only a few of the structural and operational factors of solar cells that have a major bearing on the loss processes and are therefore studied. It is shown that the loss processes are significantly impacted by variables such as the external radiative efficiency, solid angle of absorption (for example, the concentrator photovoltaic system), series resistance, and operating temperature [12].

The percentage of electricity produced by solar photovoltaics (PVs) continues to rise. Most models of PV cells take the form of circuits. Maximum power point tracking, performance assessment, and management of solar PV systems all rely on accurate calculations of circuit model characteristics of PV cells. Researchers are very interested in the "PV cell model parameter estimation problem," which entails determining values for the circuit model parameters of solar PV cells. In this study, we categorize previous studies into three groups and discuss their contributions to the field of PV cell model parameter estimation. Some suggestions for further study are made based on the results of the review [5].

To better simulate, evaluate, regulate, and optimize solar cell systems, a precise mathematical model is vital. Non-linear solar cell models make it difficult for conventional optimization techniques to pin down the true source of the problem.

2. Ideal Model of PV Cell

The following is the corresponding layout diagram for a PV cell in the SDM model: The following is the corresponding layout diagram for a PV cell in the SDM model

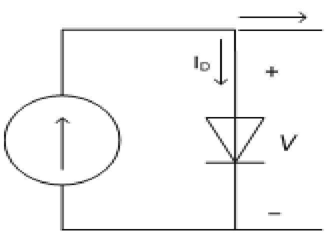

Fig.2. : Ideal PV Cell Model[5]

As illustrated in the picture, a perfect PV cell consists of a photocurrent source in shunt with a single diode, the current from which is calculated using the formula

$$I = I_{pv,cell} - \frac{I_{o,cell}[\exp(\frac{qV}{akT}) - 1]}{I_d} \quad (1)$$

$$I_d = I_{o,cell}\{\exp\left[\frac{qV}{A} * k * T\right] - 1 \quad (2)$$

The temperature coefficient of a PV module with N cells connected in series is VT (=NS*k*T/q), where q is the electron charge (1.60217646*1019 C), k is the Boltzmann constant (1.3806503*1023 J/K), T is the temperature of the p-n junction in Kelvin, and an is the ideality factor. I0 is the reverse saturation current.

3. Single Diode Model (SDM) of PV Cell

Dual currents are commonly mixed in the presence of a non-physical diode ideality factor n due to the linear independence of the diffusion and recombination currents. The SDM model is another name for this approach. A monolithic photovoltaic cell, when not exposed to light, acts just like a semiconductor diode. There is a lot of talk about utilizing this model to characterize the static I-V characteristic, and it has been used to successfully accommodate experimental findings [8].

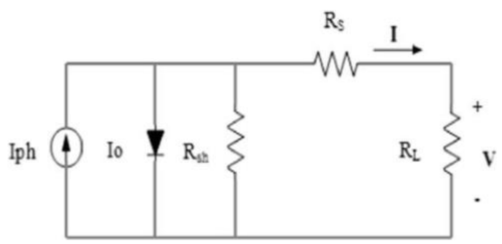

Fig.3. Equivalent circuit of PV cell

The PV cell electrical modeling of SDM includes a parallel non-ideal diode (Io), a series resistance (Rs), a shunt-connected resistance (Rsh), and a current source (Iph). The three variables ideality factor (a), diode saturation current (Id), and photocurrent (Iphoto) represent the inherent limitations of the photovoltaic cell. The losses in the quasi-neutral zone were represented by the five evaluation parameters for the SDM model. The ideality factor, often known as the absorption coefficient or q-factor, is dependent on the Its average range is 1-2, although it can go higher depending of the semiconductor material and production process. Since it is often assumed that n is 1, its absence is common. For a device whose operation is based almost entirely on the interfacial tension of such radiation, the photo-generated current, Iph, formed when the semiconductor diode is illuminated produces a longitudinal shift in the current-voltage curve.

This I-V characteristic of a linked diode allows it to behave like a perfect cell when a current source is applied. A series of algebraic equations may be obtained from the following that express the total photovoltaic current in SDM. Its average range is 1-2, although it can go higher depending of the semiconductor material and production process. Since it is often assumed that n is 1, its absence is common.

The photo-generated current, Iph, that is created when the semiconductor diode is lit causes a longitudinal shift in the current-voltage curve for a component whose performance is nearly entirely dependent on the interfacial tension of such radiation. Connecting a current source to a connected diode with this I-V characteristic mimics the behavior of an ideal cell. The total photovoltaic current in SDM may be expressed as a set of algebraic equations, which can be derived from the following. semiconductor material and production method to define its typical range of 1 to 2 but may occasionally be higher. It is frequently omitted since it is presumed that n is roughly equal to 1.

The longitudinal displacement of the current-voltage curve for a component which is almost completely linked to the interfacial tension of such radiation emitted is brought about by the photo-generated current, Iph, that is produced when the semiconductor diode is illuminated.To simulate an ideal cell, a current generator is linked to a coupled diode with such an I-V characteristic. Where ‘V’ reflects the overall output potential of the photovoltaic cell, ‘a’ indicates the diode ideality factor, and ‘Id’ represents the diode saturation current of the SDM. Consequently, the five unknown variables are as Iphoto, a, Id, Rp, *R*s are estimated by plotting the graph between V and I for different values. And it is noted that when the data are within the range of a standard experimental procedure, the derived n, Rs, Rsh, and Iph have extremely few proportion flaws. The retrieved "I" possesses weak positive proportion flaws whenever the noise level is less than 3%, but "I" has problems whenever the noise exposure is larger.

4. Other PV Cell Models

Additional models for PV cells have been presented in the literature besides the ones already listed. Some examples of such models are the single-diode-with-capacitance model, the three-diode model, the modified two-diode model, the drift-diffusion model, and the multi-dimensional diode model. However, because to their complexity, these models are rarely used for PV cell modeling.

Manufacturers of PV cells often list the cell's VOC, ISC, Pmp, KI, and KV. The information is released under typical testing conditions. To begin PV cell simulation, a model should be chosen that strikes a good balance between detail and ease of use. Model parameters are essential for simulation of PV cells and arrays, so after the right one has been chosen, it's time to figure out the circuit model parameters. Estimating PV cell model parameters from datasheet or experimental I-V data is known as the "PV cell model parameter estimation problem." Finding model parameters that give high precision in simulations is of utmost importance and significance since the accuracy of values of PV cell model parameters impact efficiency and maximum power point tracking computations. Therefore, scientists have shown a great deal of interest in studying this issue.There are several approaches to calculating PV cell properties. However, an analytical approach is taken in this body of work. Its average range is 1-2, although it can go higher depending of the semiconductor material and production process. Since it is often assumed that n is 1, its absence is common.

The photo-generated current, Iph, that is created when the semiconductor diode is lit causes a longitudinal shift in the current-voltage curve for a component whose performance is nearly entirely dependent on the interfacial tension of such radiation.

Connecting a current source to a connected diode with this I-V characteristic mimics the behavior of an ideal cell. The total photovoltaic current in SDM may be expressed as a set of algebraic equations, which can be derived from the following.

5. Conclusion

This article examines the process of collecting the variables of illuminated photovoltaic cells, which involves a series resistance and a shunt conductance. The proposed method is based on the observed or predicted values of the current-voltage parameters. The results are consistent with common sense and prior research. However, the procedure is still extremely accurate, barring any electromagnetic interference or unanticipated inaccuracies in the recorded I-V values. The proposed method is easily automated, requires little in the way of prior knowledge of the relevant qualities, and makes less stringent demands on the precision of the measured result. Diode saturation current (Id), photocurrent (Iphoto), ideality factor (), shunt resistance (Rsh), and series resistance (Rse) may all be calculated using the aforementioned formulas for the Single Diode Model (SDM).

References:

1. R. Z. Caglayan, K. Kayisli, N. Zhakiyev, A. Harrouz, I. Colak, “A review of hybrid renewable energy systems and MPPT methods”, International Journal of Smart Grid-ijSmartGrid, 2022 Sep 30, 6(3), 72-8.

2. A. Harrouz, A. Temmam, M. Abbes, “Renewable energy in algeria and energy management systems”’ International Journal of Smart Grids, ijSmartGrid. 2018 Mar, 2(1), 34-9.

3. A. Harrouz, A. Temmam, M. Abbes, “Renewable energy in algeria and energy management systems”’ International Journal of Smart Grids, ijSmartGrid, 2018 Mar, 2(1), 34-9.

4. K. Premkumar, D. Shyam, D. Sivamani, "Design and Implementation of Standalone Solar PV fed Induction motor drive for Water pumping application"’ International Transaction on Power and Energy Systems 1.1 (2021), 59-69.

5. J. Zhang, M. Zhang, Y. Li, J. Qin, K. Wei, and L. Song, “Analysis of wind characteristics and wind energy potential in complex mountainous region in southwest China,” Journal of Cleaner Production, vol. 274, pp. 123036, November 2020.

6.P.P. Kumar, R.P. Saini, “Optimization of an off-grid integrated hybrid renewable energy system with different battery technologies for rural electrification in India”, J. Energy Storage 32 (2020), https://doi.org/10.1016/j.est.2020.101912 101912.

7.Barakat, S., Ibrahim, H., Elbaset, A.A., “Multi-objective optimization of grid-connected PV-wind hybrid system considering reliability, cost, and environmental aspects”, Sustain. Cities Soc. 60, 102178, 2020.

8.Y. Yang, K. A. Kim, F. Blaabjerg, and A. Sangwongwanich, “PV system modeling, monitoring, and diagnosis,” in Advances in GridConnected Photovoltaic Power Conversion Systems, Cambridge: Woodhead Publishing, 2018, pp. 45–74.

9.K. Ishaque, Z. Salam, H. Taheri, and Syafaruddin, “Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model”, Simulation Modelling Practice and Theory, vol. 19, no. 7, pp. 1613–1626, 2011, doi: 10.1016/j.simpat.2011.04.005.

10.M. Uzunoglu, O. C. Onar, and M. S. Alam, “Modeling, control and simulation of a PV/FC/UC based hybrid power generation system for stand-alone applications”, Renewable Energy, vol. 34, no. 3, pp. 509– 520, 2009, doi: 10.1016/j.renene.2008.06.009.

11.B. Adebanji, A. Ojo, T. Fasina, S. A. Adeleye, and J. Abere, “Integration of Renewable Energy with Smart Grid Application into the Nigeria’s Power Network: Issues, challenges, and opportunities” European Journal of Engineering and Technology Research, 7(3), 18-24, 2022.

12. S. H. Antwi, and D. Ley, “Renewable Energy Implementation in Africa Ensuring Sustainability through Community Acceptability”, Scientific African, 11, 1-10, 2021.

13.E. Y. Asumah, S. Gyanfi, and A. Dagoumas, “Potential of meeting electricity needs of Off-Grid Community with mini-grid solar systems”, Scientific African, 11, 1-10, 2021.

14.O. D. Atoki, B. Adebanji, A. Adegbemile, E. T. Fasina, and O. D. Akindele, “Sustainable Energy Growth in Nigeria: The role of Grid-connected hybrid power system”, International Journal of Scientific and Technology Research. 9(9), 274-281, 2020.

15.O. E. Diemuodeke, Y. Mulugetta, H. I. Njoku, T. A. Briggs, and M. M. Ojapalu, “Solar PV Electrification in Nigeria: Current Status and Affordability Analysis”, Journal of Power and Energy Engineering. 9, 11-25, 2021.

16.G. Kamalapur, and R. Udaykumar, “Rural Electrification in India and feasibility of Photovoltaic Solar home Systems”, International Journal of Electrical Power and Energy Systems. 33(3), 594-599, 2011.

17.M. M. Mahmoud, and I. H. Ibrik, “Techno-economic feasibility of energy supply of remote villages in Palestine by PV Systems, diesel generators and electron grid”, Renewable and Sustainable Energy Reviews. 10(2),128-138, 2006.

18.A. H. Mirzahosseini, and T. Taheri, “Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran”, Renewable and Sustainable Energy Reviews. 16, 2806– 2811, 2012.

19.O. S. Ohunakin, “Energy Utilization and renewable Energy Utilization and Renewable Energy Sources in Nigeria”, Journal of Engineering Application and Science. 5(2), 171-177, 2010.

20.O. E. Olabode, T. O. Ajewole, I. K. Okalewu, A. S. Alayande, D. O. Akinyele, “Hybrid Power System for Off-Grid Locations: A Comprehensive Review of Design Techniques, Applications and Future Trends”, Scientific African. 13, 1-17, 2021.

21.M. Zhou, S. Cheng, Y. Feng, W. Xu, L. Wang, W. Cai, "Full- Order Terminal Sliding-Mode based Sensorless Control of Induction Motor with Gain Adaptation”, IEEE Journal of Emerging and Selected Topics in Power Electronics, doi: 10.1109/JESTPE.2021.3081863.

22.B. Prathap Reddy, A. Iqbal, S. Rahman, M. Meraj, S. Keerthipati, "Dynamic Modelling and Control of Pole-phase Modulation based Multiphase Induction Motor Drives”, IEEE Journal of Emerging and Selected Topics in Power Electronics (2021).