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Enhancement of Power Quality through the Implementation of a Hybrid Artificial Intelligence Model within Solar-Wind Energy Systems

Abstract: - The generation of electricity is significantly assisted by hybrid solar-wind power systems, which also play a crucial role in the advancement of intelligent grids. Furthermore, the integration of wind and solar energy storage control systems, in conjunction with energy markets, has rendered the electricity grid more economically feasible. To meet the growing demand for electricity, hybrid renewable energy systems connected to microgrids consist of substantial identifying elements. The issue of harmonic distortion in microgrids arising from nonlinear loads is a fundamental area of research. Understanding the impact of microgrids on power quality is also of great importance. This study focuses on enhancing power quality in solar-wind hybrid systems by incorporating emerging Artificial Intelligence (AI) methodologies.

The proposed approach comprises two main components: (i) detection of distortions caused by voltage fluctuations and (ii) improvement of power quality through an AI-based control system. Initially, power distortions are identified and eliminated using the Enhanced Kalman Filter (EKF) algorithm. A Hybrid Artificial Neural Network with Fuzzy Intelligence (HANFI) model is then developed based on this power data. This model integrates two prominent neural network architectures with fuzzy systems. Experimental validation of the system is conducted using MATLAB, which facilitates the simulation of hybrid energy systems.

Keywords: Power Quality, Renewable Systems, AI, ANN, Fuzzy, Solar-Wind Systems.

I. INTRODUCTION

Energy is basic to our way of life not only for the upkeep of our way of life yet in addition as the establishment for each of different parts of our economy. The increasing expenses and developing stresses over the effect on the climate presented by customary types of electrical energy. There has been a new increase in interest in different sorts of sustainable power. Across the globe in which we live, various societies have obtained a huge interest for the utilization of electrical energy. This need has been prodded by the overall straightforwardness with which power can be made, conveyed, and utilized, as well as by the huge variety of utilization that might utilize it. In spite of the fact that it very well may be discussed whether there ought to be unlimited development in how much power that is utilized, the reality of the situation is that there is a consistently expanding need for this specific sort of energy.

It is unmistakably clear that assuming this need is to be fulfilled, the limit of the force to be reckoned with plants to produce energy should continue to grow. Most of the world's energy is created in concentrated power plants right now. These plants might get their essential fuel from coal, oil, gas, water, or fissile atomic material. Practically the world's all's power is utilized. The further improvement of procedures of age that depend on any of these supposed "customary powers" will run into various difficulties. The creation of hydro power can occur in specific genuinely ideal areas, and regardless of whether there are currently plentiful coal stores, they are not renewable.

The potential perils presented by atomic power have gotten a lot of consideration, particularly those related with the control and utilization of atomic waste in military settings. Despite this, it seems plausible that a rising atomic power presence, most likely including combination reactors as well as reproducer reactors, will be acknowledged in large numbers of our nations in order to support the most common way of saving the accessibility of electrical stock. It is essential that some piece, and a developing part, of future innovative work in the field of electrical energy be worried about purported "non-conventional" method for creation to achieve this objective and furthermore to aid the administration of the flow assets of petroleum products. To this end fundamental innovative work in the field of electrical energy be directed. Ages of power that depend on wind and sunlight based energy are turning out to be

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more conceivable for what's to come. As well as being free, there are no continuous accuses related of utilizing them.

About 70 to 80 percent of all power quality-related problems are probably the result of improper connections and/or wiring [2]. The point supplier and demand types are linked to other types of power quality issues (listed in Table 1) [3].

These problems include electrical frequency problems, electromagnetic interference, transients, harmonics, and low power factor. Harmonics stand out as the most important of these many occurrences. Harmonics' impacts on PQ are further upon in [4], which may be accessed here. The IEEE standard states that there are two different ways to minimize harmonics in the electrical system. There are two methods for calculating harmonic voltage that the utility can deliver to any customer at the point of common coupling (PCC) and the maximum amount of harmonic current that a user can inject into the utility system. The point of common coupling (PCC) determines both of these boundaries. [5]

provides further information on these restrictions. Again, DG connectivity rules have to be adhered to, taking into consideration concerns pertaining to PQ, protection, and stability [6].

II. Related Works

In this study, the findings of experimental examinations of the reliability of the energy on a ship with electric propulsion are presented. The management of dc rowing motors (RMs) aboard the ship has been carried up using high-power thyristor converters, and those converters are controlled by the ship. It has been shown that it is feasible to achieve efficient management of the electricity's quality in a non stationary system like a ship's electric-power system by using intelligent decision support systems that search for answers to the issue of multi-criteria optimization [26]. This was accomplished by a ship's electric-power network.

Electrical Distribution Utilities have a very important technological problem in the form of unpredictability and fluctuation in the output of renewable energy sources. Power quality indicators are a representation of the dependability and quality of the energy that is provided. A control strategy design is described in this paper for real-time PQ management in active distribution systems. This work was carried out by the author. The current effort focuses on the control of voltage variations brought on by the variable nature of production from renewable sources. In order to account for the cyclical nature of renewable energy sources, a strategy known as zero energy reserve is being developed. In this reactive power management technique, the power consumption of flexible loads is adjusted in order to lower the peak load on the feeder and the technical losses that are associated with it. The potential of smart inverters to provide dynamic reactive power is used in the design of a volt VAR control technique that is discussed here. It is possible to optimize the profile of voltage, cut down on technical losses, and keep the system reliable by using unbalanced power flow, varying load profiles, and flexible loads as virtual energy storage. For the purpose of control plan design confirmation, an IEEE 13 bus distributing system is used. The comparative findings point to a decrease in the technical losses of the system as well as the strain placed on the automated voltage regulators. The simplicity with which a control plan may be designed is indicative of its potential applicability in the actual world [27].

The purpose of this article is to provide a measuring method that may be used to keep track of the instantaneous frequency in power systems. For the purpose of time stamping, it employs a data gathering module in conjunction with a GPS receiver. A software written in Python is responsible for receiving the data, computing the frequency, and then ultimately uploading the measurement results to a database. All of these tasks are performed automatically. The article compares two distinct approaches to calculating the frequency, both of which are used to get the final result. The data that has been saved is shown with the help of the Grafana platform, which demonstrates the capacity of the platform to compare scientific data. [28] The whole of the system, when considered as a data collecting system, is an effective and inexpensive solution.

At the point when scattered breeze power and planetary groups with high penetrability are coupled to the appropriation organization, the instability and casualness of the dispersion network are intensified. Furthermore, as there is a developing requirement for warming throughout the cold weather months and there is a developing worry for the climate, the far and wide utilization of electric warm stockpiling warming gear (ETSHE) may support the double-dealing of conveyed sustainable power. Then again, an unforeseen ETSHE association with the conveyance network can possibly make critical issues with the power quality. It has been recommended that another methodology of gear situation and limit ought to be utilized, one that thinks about the upgrade of the circulation organization's power quality and burden request attributes. In the initial step of fostering the model's answer, a gauge of the hub's warm burden classification was completed utilizing innovation in view of intensity load representations. This gave the information establishment to the model. In the second step of the cycle, a multi-objective ideal situation and limit programming model was created. This model considered consonant contortion rate, voltage deviation, voltage variety, and ETSHE cost. From that point onward, the framework hubs were prepossessed in light of the awareness examination approach to eliminate the quantity of establishment hubs that should have been picked. Thus, it was feasible to secure a useful elective arrangement of establishment hubs for the ideal design model of ETSHE. Eventually, the model was settled by utilizing an upgraded multi-objective molecule swarm streamlining procedure, and the power nature of each entrance technique was assessed utilizing the information envelope investigation approach. The assessment of the mathematical model shows that in addition to the fact that it supply can the intensity interest of the client, yet it can likewise effectively upgrade the power quality by judiciously planning the position and limit of ETSHE, which eventually brings about the protected and productive utilization of energy [29]. This is shown by the way that it fulfills both of these necessities.

III. PROPOSED MODEL

3.1 System PV Model

The photovoltaic (PV) arrays are then linked simultaneously to the primary DC/AC inverter in order to generate the required amount of reactive power and to manage the active power that is injected into the electrical grid. This arrangement offers a number of benefits, including an even DC-link voltage, minimal losses, greater effectiveness, and cost-effectiveness.

Equation 1 can be used to model the total electrical power produced by a photovoltaic array. It expresses this power as a function of the incident solar radiation on the tilted PV surface, the area of the PV panel (A), and the PV's overall module efficiency (_PV). The chosen PV module's price and technical specifications are displayed below. The power losses that occur throughout the course of a PV system's lifespan due to increasing cell temperatures, dust and snow deposition, panel soiling, heat losses via wiring, and age-related performance deterioration are not included in this basic model.

These power losses may be attributed to factors such as greater cell conditions, dirt and snow buildup, panel stains, and thermal losses from wiring. Nevertheless, these losses need to be accounted for in order to provide a more physically accurate picture of the system.

This is necessary in order to guarantee the technological and economic sustainability of a photovoltaic (PV) system's actual deployment in the real world. By redefining the overall PV module efficiency, which is given in Equations (1)–(5), it is possible to take into consideration the influence of these damaging aspects in the fundamental model (Equation 1).

$$P_{pV} = SR_{tutt} * A * \eta_{pV} \quad (1)$$

$P_{PV}(\, kW)$ is comparable to the amount of power generated by a single solar photovoltaic panel.

a) Battery Model

If the entire LD cannot be satisfied by the HRES alone, the battery ESS acts as an extra power unit and as a means of storage when the total solar power production is more than the total LD and surplus energy is supplied into the battery system. In other words, the batteries ESS acts as a storage unit when the entire renewable energy generated is higher than the total LD. The fluctuating production of renewable energy is a direct result of the intermittent nature of SR resources, which highlights the need of having a battery energy management system (also known as BEMS). The evidence suggests that,

$$E_{ch}(t) = \left[E_{TREG}(t) - \left(\frac{E_L(t)}{\eta_{\frac{DC}{AC}}}\right)\right] * \eta_{ch} \quad (2)$$

$$E_{dhh}(t) = \left[\left(\frac{E_L(t)}{\eta_{\frac{DC}{AC}}^{AC}}\right) - E_{TREG}(t)\right] / \eta_{dh} \quad (3)$$

$$P_{BAT}(t) = E_{ch}(t) = -E_{dh}(t) \quad (4)$$

b) Wind System Model

If an object has a mass m and is traveling at a velocity v, then its kinetic energy, denoted by the symbol E, is equal to the amount of work, denoted by W, that is done to bring that object from a state of rest to a distance s when subjected to a force F and under circumstances of constant acceleration a, i.e. E = W = F s. The second of Newton's laws of motion states that,

$$F = m \times a \tag{5}$$

thus, the kinetic energy becomes

$$E = mas \tag{6}$$

When it comes to the kinematics of solid motion, the formula for determining v2 is as follows: v2 = u2 + 2as, where u is the initial velocity of the object. This seems to indicate that a = v2 + u + 2s. When we make the assumption that the object's initial velocity is zero, we arrive at the formula A = v2 2s. As a direct consequence of the equation shown above, we are aware that,

$$E = \frac{1}{2}mv^2 \tag{7}$$

The assumption that underlies this particular calculation for kinetic energy is that the mass of the solid remains unchanged. Fig.1 shows the proposed control system model.

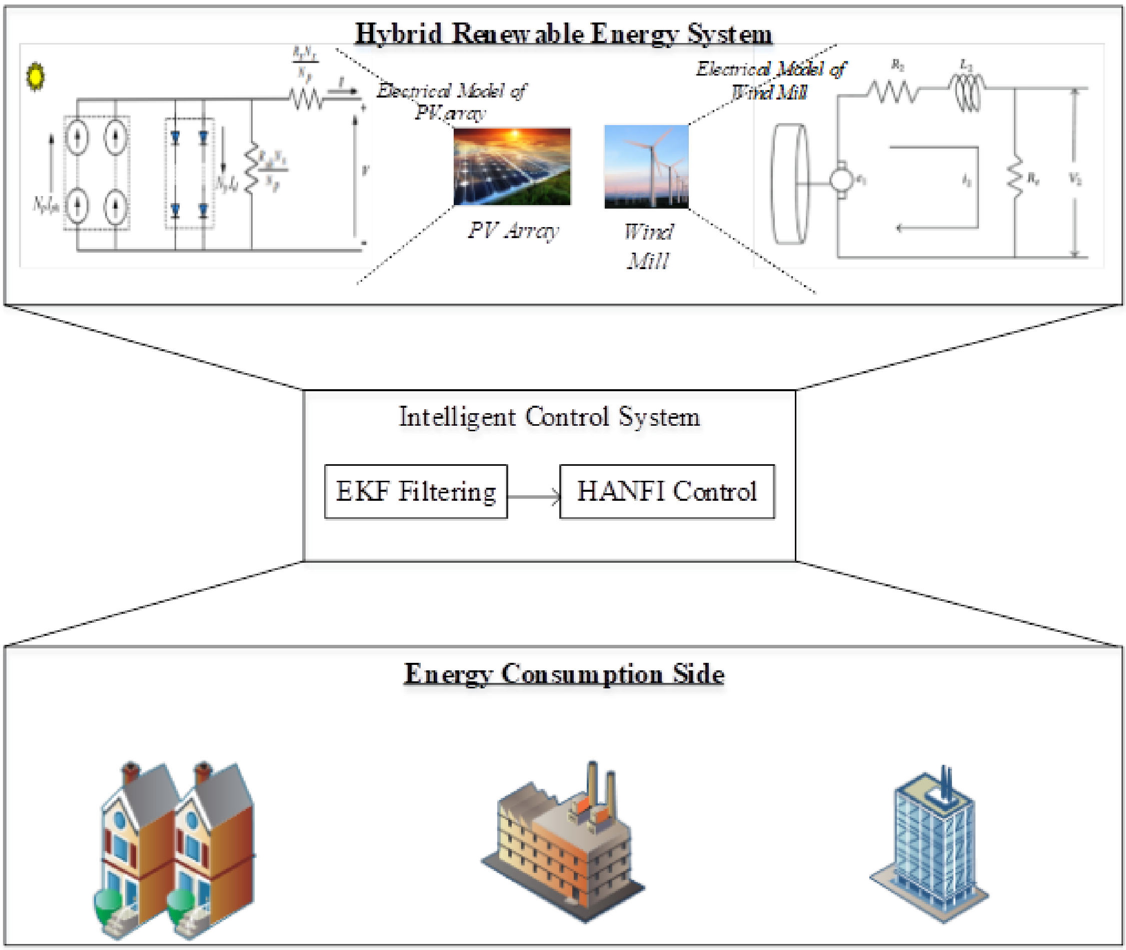

Fig. 1. Proposed Model

3.2 Data filtering

As was mentioned earlier, the goal of the sorting step is to refresh the anticipated indicate the vector at site (k) centered on the reports at sites up to (k 1) by such as the feedback at site (k), and to make it feasible to arrive at the most accurate estimate of the state vector at site (k) using all of the information that has been gathered up to that point from all of the sites up to site (k). This was mentioned before. The purpose of this is to work out a recurrence formula for this situation. The notion that the correlation matrices for the anticipated state vector (a k1 k) is provided by Eq. (2.13) suggests that anything that we are able to say about the state vector at site (k) based on what we have seen at sites up to site (k 1) can be summed up into the following single 2 equation:

Notation $\hat{x}_{n|m}$ represents the estimate of x at time n given observations up to and including at time m. The predicted state estimate is,

$$\hat{x}_{k|k-1} = f(\hat{x}_{k-1|k-1}, u_k) \;\; P_{k|k-1} = F_k P_{k-1|k-1} F_k^T + Q_k$$

Then the state update is performed as follows,

$$\tilde{y}_k = z_k - h(\hat{x}_{k|k-1}) \;\; S_k = H_k P_{k|k-1} H_k^T + R_k \;\; K_k = P_{k|k-1} H_k^T S_k^{-1} \;\; \hat{x}_{k|k} = \hat{x}_{k|k-1} + K_k \tilde{y}_k \;\; P_{k|k} = (I - K_k H_k) P_{k|k-1}$$

using the following definitions for the state transition and observation matrices: The Jacobians.

$$F_k = \frac{\partial f}{\partial x}\Big|_{\hat{x}_{k-1|k-1}, u_k} \;\; H_k = \frac{\partial h}{\partial x}\Big|_{\hat{x}_{k|k-1}}$$

3.3 Intelligent power control system

An adaptive neuro-fuzzy inference system (ANFIS) or adaptive network-based fuzzy inference system (ANFIS) is a type of artificial neural network that is built on a Takagi–Sugeno fuzzy inference system. It can capture the benefits of both inside a single framework since it combines the ideas of fuzzy logic with neural networks. The network's structure can be divided into two separate sections, known as the premise parts and the consequence parts, respectively. To be more precise, the architecture is divided into five levels.

The first layer processes the input values and finds the membership functions that correspond to those values based on those values. The term "fuzzification layer" is widely used to refer to this layer. Calculating the number of levels of each function requires utilizing the premise parameter set, which consists of the letters a, b, and c. The second layer is responsible for producing the firing strengths that are mandated by the regulations. The second layer is called the "rule layer" since it is in charge of enforcing regulations. The role that the third layer performs in the process is to normalize the calculated firing strengths by dividing each value by the total firing strength. The 4th layer receives the normalized numbers as inputs and the generated variable set "p,q,r" as its respective inputs.

. The outcomes that are produced by this layer are the ones that have been defuzzified, and those values are then passed on to the last one, which is responsible for producing the final output.

The distinction between a vanilla neural network and an ANFIS network is outlined in the first layer of an ANFIS network. In overall, neural networks begin their operation with a phase known as data prepossessing, during which the characteristics are transformed into normalized values that fall somewhere in the range of 0 to 1. Even though it does not need a sigmoid function, an ANFIS neural network nevertheless performs the step of preprocessing by transforming numerical inputs into fuzzy values. The following is a description of the IF-THEN rules for a Takagi-Sugeno system with three inputs.

(i) Rule 1: $IF\ x\ is\ A1,\ y\ is\ B1,\ z\ is\ C1, THEN\ F_1 = p_1x + q_1y + r_1z + s_1$

(ii)Rule 2: $IF\ x\ is\ A2,\ y\ is\ B2,\ z\ is\ C2,$ THEN $F_2 = p_2x + q_2y + r_2z + s_2$

(iii)Rule 3: $IF\ x\ is\ A3,\ y\ is\ B3,\ z\ is\ C3,$ THEN $F_3 = p_3x + q_3y + r_3z + s_3$

where x, y, z are the inputs in the crisp set; A_i, B_i, C_i are the linguistic labels; p_i, q_i, r_i are the consequent parameters; f_1, f_2, f_3 are the output fuzzy membership functions.

In this particular layer, which is known as the Output Layer, there is just one neuron present for the output, which is the total of all the inputs. The following is how you compute the output of the node:

$$OP = f(x, y, z) = \sum_i w_i f_i$$

During the time that the final output is being computed, the backward pass will begin. This is the phase in which the mistake will be sent to Layer 1 and the initial variables will be modified. During this stage, the following variables are held at their default values.

IV. Experimental Analysis

In order to simulate the system, MATLAB was used. The data was extracted with the help of C++. The output file was included inside the spreadsheet file. The results of running the code are shown in the corresponding excel file. The THD value expressed in both current and voltage will be shown in the corresponding excel file. The FL algorithm was used to do the division of the data into current and voltage values. Compilation of the results of the simulation was completed. It is feasible to make changes to the code in order to extract values that are more relevant. The simulation table provides a rundown of the many types of PQ disturbances that were triggered by the system. These interruptions were specified using the categories of events that occurred as well as their values.

4.1 Comparative Analysis

The bulk of the control technique's transient qualities are determined by the gains and coefficients that are found in the algebraic Riccati equation for the method, which may be found in Eq. (84). When gain r is given relatively small values, the tracking error of the state vector may in fact be removed for all reference set points. In addition, with relatively high values of the diagonal elements of the positive semi-definite symmetric matrix Q, one experiences rapid convergence of the state variables to their set points. Finally, but certainly not least, having low values for increases the control system's resistance to failure.

The minimum value of for which it is possible to achieve a proper solution to the aforementioned Riccati equation in the form of a positive-definite and symmetric matrix P is what is considered to offer the control loop with the utmost amount of resilience possible. The nonlinear optimal control approach (H-infinity) that was proposed exhibits characteristics of global (rather than local) stability.

It is possible to discern this using simulation studies due to the fact that the state variables of the six-phase induction generator have the ability to monitor time-varying and rapidly changing set points and converge to these set points independently of the conditions under which they were first measured.

The control approach ensures optimal operation of the 6-phase induction generator-based renewable energy system after reducing changes of the control inputs. This makes it possible for the 6-phase induction generator to operate with the least amount of energy dispersion possible under changeable operating conditions. The control approach ensures optimal operation of the 6-phase induction generator-based renewable energy system after reducing changes of the control inputs.

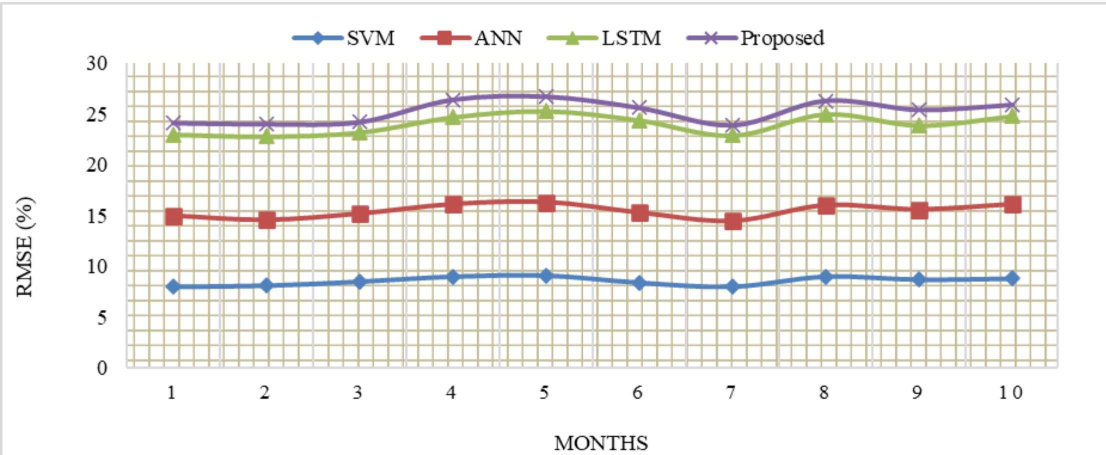

Fig. 2. RMSE analysis

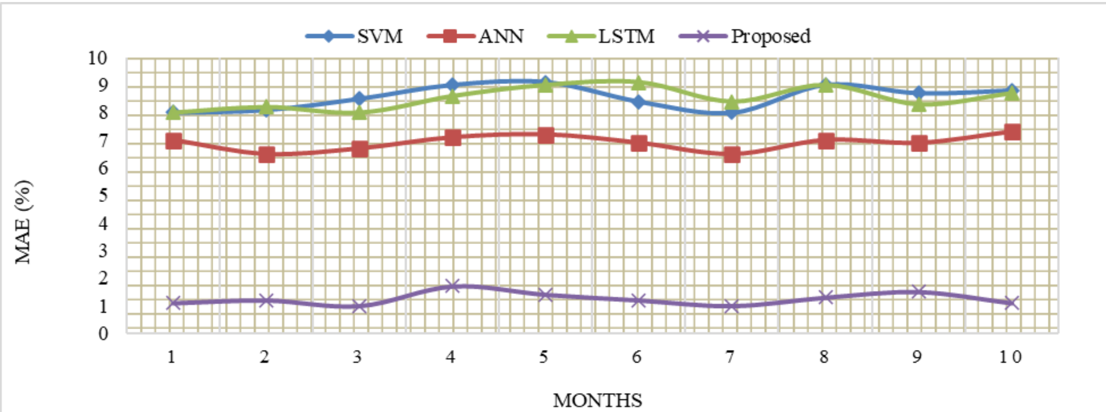

Fig. 3. MAE analysis

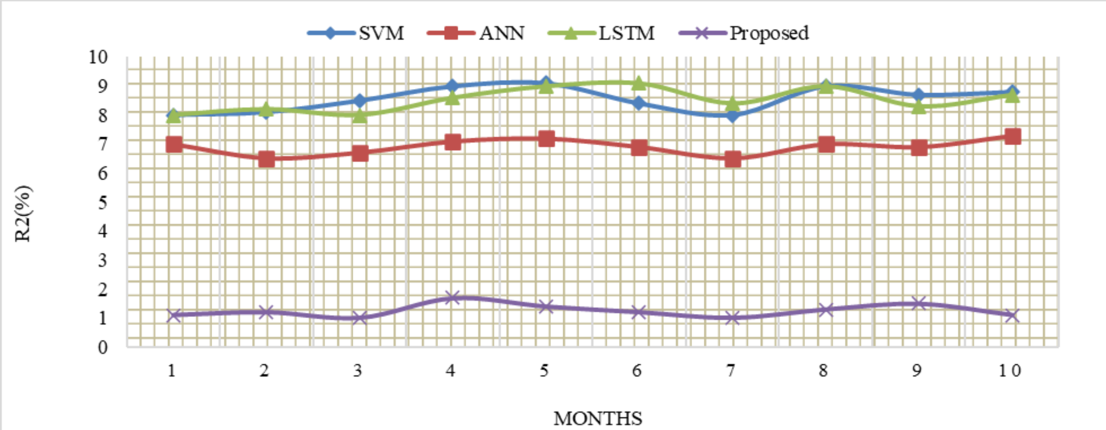

Fig. 4. R2 analysis

The recommended strategy for DRL optimal control is novel in comparison to prior solutions that were proposed for the problem of providing the optimum amount of control for the DRL dynamical system. Instead of performing linearization at points that are part of the desired trajectory (setpoints), as was the case with previous methods, the new DRL optimal control method performs linearization around a temporary operating point that is determined by the current value of the system's state vector and by the most recently sampled value of the control inputs vector. In other words, linearization is performed around a point that is determined by the system's state vector and the control inputs vector. In addition, the global stability justification for this control strategy, in addition to the Riccati equation that was used to calculate the feedback gains of the controller, are also innovative aspects of this control approach.

V. Conclution

Hybrid solar and wind power systems not only contribute significantly to the improvement of existing electrical networks but also make a significant contribution to the generation of energy. In addition, the wind and solar combined energy storage control systems, in conjunction with the various energy markets, helped to make the electrical grid more financially feasible. Large identification components are often included in hybrid renewable energy systems that are connected to microgrids. This is done in order to fulfill the ever-increasing demand for electrical power. In addition to this, it is vital for research to look at the problem of harmonic distortion in micro-grids brought on by non-linear loads. This is a subject matter that has to be looked into. In addition to this, it is of the utmost importance for gaining a better understanding of the impact that micro-grids have on the quality of the electricity they provide. In this research, we address the problem of power quality improvement in solar-wind combination systems by combining several methodologies that fall under the umbrella of artificial intelligence (AI). The suggested technique basically comprises of two primary sections, which are (i) distortion detection owing to fluctuations in voltage and (ii) power quality improvement using an AI-based control system. Both of these are important aspects of the methodology. Enhanced Kalman Filter (EKF) is the approach that is first used to identify and filter any power distortions that may have occurred. The control system is designed using a model called a Hybrid Artificial Neural Network with Fuzzy Intelligence (HANFI). This model uses the power data that is provided. The model that is being suggested integrates two well-known ANN structures with fuzzy systems. Experiments are run via MATLAB, which allows for the simulation of hybrid energy systems. This is done for the purpose of validating the system.

References

[1] Sadeghi, Delnia et al. "Optimal sizing of hybrid renewable energy systems by considering power sharing and electric vehicles." International Journal of Energy Research 46 (2022): 8288 - 8312.

[2] Arsad, A.Z. et al. "Hydrogen energy storage integrated hybrid renewable energy systems: A review analysis for future research directions." International Journal of Hydrogen Energy (2022): n. pag.

[3] Al-Othman, Amani et al. "Artificial intelligence and numerical models in hybrid renewable energy systems with fuel cells: Advances and prospects." Energy Conversion and Management (2022): n. pag.

[4] Kallio, Sonja and Monica Siroux. "Hybrid renewable energy systems based on micro-cogeneration." Energy Reports (2022): n. pag.

[5] Dumas, Jonathan et al. "A deep generative model for probabilistic energy forecasting in power systems: normalizing flows." Applied Energy (2021): n. pag.

[6] Lv, Qingquan et al. "Photovoltaic Power Forecasting in Dunhuang based on Recurrent Neural Network." 2021 IEEE 23rd Int Conf on High Performance Computing & Communications; 7th Int Conf on Data Science & Systems; 19th Int Conf on Smart City; 7th Int Conf on Dependability in Sensor, Cloud & Big Data Systems & Application (HPCC/DSS/SmartCity/DependSys) (2021): 1346-1352.

[7] Wu, Yuan-Kang et al. "Completed Review of Various Solar Power Forecasting Techniques Considering Different Viewpoints." Energies (2022): n. pag.

[8] Zhang, Yujia et al. "Implementation of Maximum Power Point Tracking Based on Variable Speed Forecasting for Wind Energy Systems." Processes (2019): n. pag.

[9] Zhang, Rongquan et al. "A hybrid deep learning model with error correction for photovoltaic power forecasting." Frontiers in Energy Research (2022).

[10] Liu, Chun-Hung et al. "A Simplified LSTM Neural Networks for One Day-Ahead Solar Power Forecasting." IEEE Access 9 (2021): 17174-17195.

[11] "More than accuracy: end-to-end wind power forecasting that optimises the energy system." Electric Power Systems Research (2023): n. pag.

[12] Xu, Shiwei. "Coastal Wind Power Forecasting Research Scheme Design." Frontiers in Computing and Intelligent Systems (2022): n. pag.

[13] Perera, A. T. D. and Parameswaran Kamalaruban. "Applications of reinforcement learning in energy systems." Renewable and Sustainable Energy Reviews (2021): n. pag.

[14] Yang, Ting et al. "Reinforcement learning in sustainable energy and electric systems: a survey." Annu. Rev. Control. 49 (2020): 145-163.

[15] Jogunola, Olamide et al. "Consensus Algorithms and Deep Reinforcement Learning in Energy Market: A Review." IEEE Internet of Things Journal 8 (2020): 4211-4227.

[16] Rahul, Immadisetty, and Raju Hariharan. "Enhancement of Solar PV Panel Efficiency Using Double Integral Sliding Mode MPPT Control." Tsinghua Science and Technology 29.1 (2023): 271-283.

[17] Vignesh, T., and R. Hariharan. "Design and performance analysis of three phase solar PV integrated UPQC." AIP Conference Proceedings. Vol. 2426. No. 1. AIP Publishing, 2022.

[18] Kumar, MVNR Pavan, and R. Hariharan. "Improved trustworthy, speed, and energy-efficient GPSR routing algorithm in large-scale WSN." Measurement: Sensors 24 (2022): 100576.

[19] Kumar, MVNR Pavan, and R. Hariharan. "SPEED-UP, and energy-efficient GPSR protocol for WSNs using IOT." Measurement: Sensors 23 (2022): 100411.

[20] Rahul, I., and R. Hariharan. "Enhancement of Solar PV Panel Using Single Integral Sliding Mode MPPT Control." International Journal of Integrated Engineering 14.6 (2022): 281-289.

[21] Dathu, K. P. M. Y. V., and R. Hariharan. "Modelling of plug-in hybrid electric vehicle (PHEV) with multi source." Materials Today: Proceedings 44 (2021): 4020-4023.

[22] Vinitha, K., et al. "Review on industrial mathematics and materials at Industry 1.0 to Industry 4.0." Materials Today: Proceedings 33 (2020): 3956-3960.

[23] Dathu, K. P. M. Y. V., and R. Hariharan. "Design of wind turbine blade material for higher efficiency." Materials Today: Proceedings 33 (2020): 565-569.vSukraj, K., et al. "Optimization of the Size of Dstatcom System Based on Data–Driven Control Design."

[24] Rajesh, S., R. Hariharan, and T. Yuvaraj. "Cuckoo search algorithm based critical load restoratinwith dgr using virtual instrumentation." Int. J. Innov. Technol. Explor. Eng (2019). Sukraj, K., et al. "Simultaneous allocation of shunt capacitor and distributed generator in radial distribution network using modified firefly algorithm." 2019 International Conference on Smart Structures and Systems (ICSSS). IEEE, 2019.

[25] Hariharan, R., P. Usha Rani, and P. Muthu Kannan. "Sustain the critical load in blackout using virtual instrumentation." Intelligent and Efficient Electrical Systems: Selected Proceedings of ICIEES'17. Springer Singapore, 2018.

[26] Hariharan, R., and P. Usha Rani. "Blackout restoration process by PHEV charging station integrated system using virtual instrumentation." 2017 Fourth International Conference on Signal Processing, Communication and Networking (ICSCN). IEEE, 2017.

[27] Gowtham, S., M. Hemanth, and R. Hari Haran. "A Review on Power System Stability Analysis & Control by Intelligence System." Indian Journal of Public Health Research & Development 8.4 (2017).

[28] Hariharan, R., and P. Usha Rani. "Optimal Generation Start-Up strategy for Blackout Restoration Using Virtual Instrumentation." Indian Journal of Public Health Research & Development 8.4 (2017).

[29] Sowmiya, N., P. Nandhini Devi, and R. Hariharan. "Review on Challenges Facing on Smartd grid Overcome by Intelligence System." Indian Journal of Public Health Research & Development 8.4 (2017): 1111-1117.