POWER FLOW CONTROL IN GRID CONNECTED PV SYSTEM INTENDED FOR RURAL INDUSTRIES WITH ANN CONTROLLER

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ABSTRACT:
With the rising demand for non-conventional energy sources and the integration of photovoltaic (PV) systems into the power grid, effective control mechanisms are essential to enhance grid stability and optimize power quality. So, An Artificial Neural Network adapted control section for the three-phase inverter is proposed to manage the power flow in the grid connected PV system. A Single Ended Primary Inductor Converter (SEPIC) is employed to efficiently manage the varying output of solar panels while ensuring a consistent voltage level for the inverter. The ANN is implemented to autonomously adjust the inverter output based on real time measurements of power demand and solar generation, enabling precise regulation of both real and reactive power in rural industries. The execution of the ANN adapted control strategy is evaluated through simulations conducted in MATLAB Simulink environment. The results indicate significant improvements in system efficiency, response time and stability under fluctuating environmental conditions. The ANN effectively adapts to changing grid requirements, thereby ensuring optimal energy transfer and enhancing overall system reliability. This research demonstrates the viability of integrating ANN-based control techniques in solar power systems, contributing to more robust and intelligent energy management solutions in the context of smart grids.
Keywords: Artificial Neural Network, SEPIC, Power Flow Control, Grid connected PV system, Rural industries.

INTRODUCTION:
The integration of renewable energy sources into the power grid has gained significant attention in recent years due to the increasing demand for clean and sustainable energy. Among these renewable sources, photovoltaic (PV) systems have emerged as a popular choice for power generation, especially in rural and remote areas, where extending conventional grid infrastructure can be both expensive and challenging. Rural industries, which often operate with limited access to reliable energy, stand to benefit immensely from grid-connected PV systems, enabling energy independence, reduced costs, and enhanced productivity. Efficient power flow control in grid-connected PV systems is critical to ensure stable and optimal operation. The intermittent nature of solar energy, combined with varying load demands, poses significant challenges to maintaining a balanced and reliable power supply. Advanced control strategies are, therefore, necessary to optimize energy utilization, improve power quality, and ensure seamless integration of the PV system with the grid.This research work presents an intelligent power flow control framework for grid-connected PV systems, specifically designed to meet the needs of rural industries. The proposed system employs an Artificial Neural Network (ANN)-based controller, leveraging its ability to handle nonlinearities, adapt to changing environmental conditions, and make real-time decisions for efficient power management. The ANN controller is designed to regulate power flow, enhance the stability of the grid interface, and ensure optimal performance of the PV system under varying operating conditions [1] [2].

EXISTING WORK:
The integration of photovoltaic (PV) systems into the grid has been extensively studied due to the growing demand for clean and sustainable energy. Numerous works have focused on optimizing grid-

connected PV systems to address challenges such as maximum power point tracking (MPPT), voltage regulation, and grid stability. However, existing methods often lack adaptability to dynamic conditions, especially in rural industrial environments where power demand can vary significantly. Below, we review relevant works and identify their limitations compared to our proposed ANN-based power flow control approach.

A fractional PI controller is designed for three-phase grid-connected PV systems using an optimization-based approach. While the fractional-order controller improves stability and precision, it suffers from high computational complexity, which makes it unsuitable for rural industries with limited computational infrastructure. Additionally, the study does not consider the fluctuating load patterns often observed in rural settings, limiting its practical application [3]. An enhanced perturb and observe (P&O) method for MPPT and power stabilization is proposed in grid-connected PV systems. Although this method achieves improved MPPT efficiency, its performance degrades under rapidly changing environmental conditions. Moreover, the approach primarily focuses on MPPT and does not address comprehensive power flow control mechanisms, which are critical for managing variable power demands in rural industries [4]. A two-stage single-phase grid-connected PV system with simplified power regulation is presented. The system reduces complexity and ensures stable power output. However, the single-phase configuration is not suitable for large-scale applications, such as rural industries that require three-phase systems for their machinery. Furthermore, the absence of an intelligent control mechanism, such as an ANN, limits its ability to adapt to varying load conditions [5]. By the use of a proportional-integral (PI) controller, the design of a three-phase grid-connected PV inverter is done. Although the PI controller ensures stable operation under steady-state conditions, it lacks adaptability in dynamic environments. PI controllers are not inherently designed to handle the rapid variations in load and generation commonly encountered in rural industrial applications, making the system less reliable in such contexts [6].A fractional-order controller prototype is introduced for grid-tied PV systems. While fractional-order controllers offer enhanced flexibility, they are computationally intensive and complex to implement, making them less viable for cost-sensitive rural industries. Additionally, the study does not incorporate intelligent control algorithms, such as ANN, which could provide better adaptability to changing load and generation profiles [7]. A fuzzy-based low-voltage ride-through (LVRT) strategy is developed for three-phase grid-connected PV systems. The fuzzy controller enhances system resilience during voltage sags. However, it lacks precision in power flow control and does not adequately address the need for dynamic load management in rural industrial environments. The reliance on rule-based fuzzy logic also limits the scalability and adaptability of the system [8]. A voltage control method is proposed for PV grid-connected systems based on a tracking differentiator. This method improves voltage stability and ensures smooth operation under grid fluctuations. However, it does not provide a robust power flow control mechanism, which is essential for balancing generation and demand in rural industries with variable load profiles [9]. A modular multilevel converter (MMC)-based PV grid-connected system integrated with a hybrid energy storage system using superconducting magnetic energy storage (SMES) and batteries is investigated. While this approach enhances energy management and stability, the system's high cost and complexity pose significant barriers for rural industrial applications. Additionally, the study does not incorporate intelligent control strategies, such as ANN, to optimize power flow effectively [10].

PROPOSED WORK:

Overview:

The suggested system combines an Artificial Neural Network (ANN) control technique with a grid-connected solar power configuration that includes a single ended primary inductor converter (SEPIC) and a three-phase inverter. This design seeks to maximize actual and reactive power management, assuring efficient operation and grid compliance while resolving the issues associated with solar power

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generation fluctuation installed for supply of power to load in rural industries. The schematic of the proposed system is given in figure 1.

SYSTEM ARCHITECTURE:

The suggested system's architecture is made up of several key components, each of which contributes significantly to its functionality. The system's foundation is built around Solar Photovoltaic (PV) Panels, these panels obtain solar energy and change it into direct current (DC) electricity. A Single Ended Primary Inductor Converter (SEPIC) is used as a voltage regulator, changing up or down the voltage to maintain a stable output and ensure that the inverter receives consistent input. The Three-Phase Inverter is the next crucial component, since it converts the SEPIC converter's regulated DC output into alternating current (AC) that may be integrated into the electrical grid. The ANN Controller functions as the system's brain, handling both real and reactive power output. By continuously processing data from the solar panels, grid parameters, and system performance indicators, the ANN may adaptively alter the inverter's output in response to changing conditions, thus improving the system's overall efficiency and dependability.

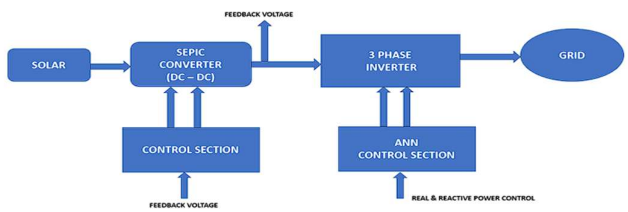

Figure 1: The schematic of the proposed system

SIMULATION ENVIRONMENT :

The suggested system will be fully simulated using MATLAB Simulink, a powerful tool for modeling and evaluating dynamic systems. The simulation environment enables rigorous testing of various system configurations and control tactics, resulting in insights into performance under diverse operational conditions. During the simulation, dynamic testing will be conducted to assess the system's reaction to sudden changes in solar irradiance, such as those induced by passing clouds or seasonal variations. In addition, load demand scenarios will be simulated to assess how well the system reacts to changes in energy use. These tests will assist in identifying any potential issues with stability and responsiveness. Table 1 shows the different parameters used in the simulation.

Table 1: Simulation Parameters

Parameters	**Values**
Cells per module	72
Open Circuit Voltage of PV panel	43.5 V
Short Circuit Current of PV panel	5.25 A
Parallel strings	10
Series connected modules per string	12
PV array output voltage	480.5 V
Boost converter output voltage	700 V
Inductive filter	1 mH
RC filter	1 Ω, 40 μF
Industrial load	1 kW
Switching frequency (F_s)	1kHz

SIMULATION AND RESULTS:

Simulation

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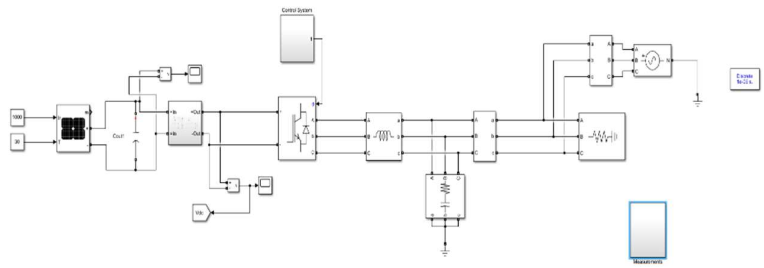
The detailed view of simulation can be seen in figure 2. The power produced from the PV array is around 10 kW. The output voltage is around 480.5 V. The voltage is too low for the inverter, so the SEPIC converter is utilized to boost the voltage. The output voltage of the boost converter is around 700 V. After the voltage is boosted, the power supply is given to the three-phase inverter. The ANN



control section is giving the required switching pulses for the MOSFETs that are present in the inverter. So, the switching is done based on the real and reactive power of the grid. The output power from the inverter is then given to a 1 kW resistive load in industry. The excessive power is then given to the electrical grid. The power injected to the electrical grid is around 9 kW.

Figure 2: Overall simulation of the proposed system

The subsystem of the SEPIC converter can be seen in figure 3. The gate pulse to the MOSFET is given by the PI controller. The input to the PI controller is the actual output value of the SEPIC converter and the desired value. The output is put into closed loop system to regulate the constant output voltage. The purpose of the SEPIC converter is to boost the output voltage from the solar panel. The LC filters are used for the smoothing out the output voltage from the SEPIC converter.

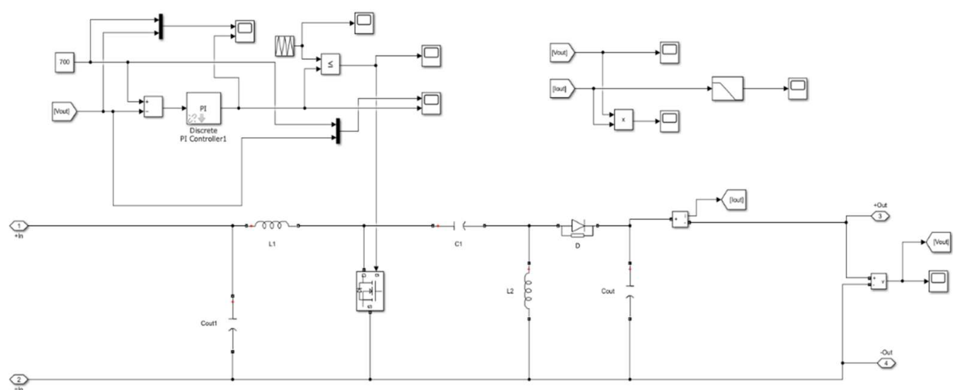
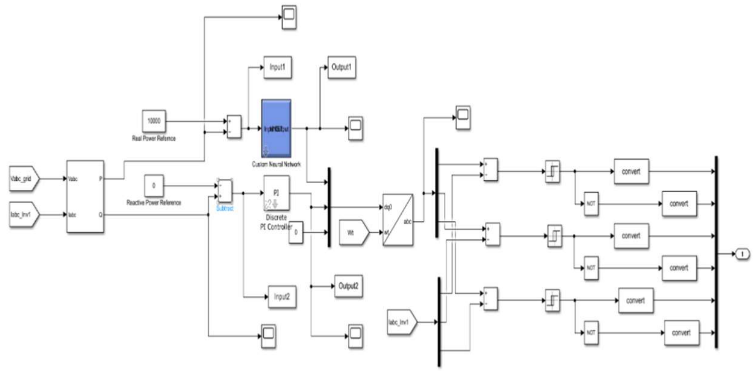


Figure 3: Subsystem of the SEPIC converter block

The subsystem of the ANN based controller is shown in figure 4. It is used to give the firing pulse to the MOSFET of the 3-phase inverter. The switching of those six MOSFETs are done based on the inverter voltage and current. The hidden layers of the ANN can be seen in figure 5. The input to the custom neural network block is the difference of the reference value and the actual value of output real power of the inverter. The PI controller's input is the output reactive power of the inverter. The ANN and PI controller provides the control signal based on the input provided to it. These control signals are multiplied with the use of multiplexer (mux) block along with a constant block with the value of 0.

The inverse park's transformation block is added to change the rotating reference frame components to stationary reference frame components. The angular position of the rotating frame is taken as input to the inverse park's transformation with the use of ωt block in rad. The value of ωt is taken from the grid's output voltage with the help of PLL block. The output from the inverse park's transformation block is given to the demultiplexer (demux) block to split the abc components into three values and the output of the three-phase inverter current is given to another demux block to split the three phases of the current into single each phase.

The first port of the top and bottom demux block is given to the sum block and the error signal from the sum block is given to the relay for the switching of two specified values. Next the value is converted



to the recognizable switching pulses for the MOSFETs that are present in the three-phase inverter. The harmonics that are present in the output voltage of the inverter is filtered out by the use of filters that are present in series and parallel with the three-phase line of the grid. An industrial load is connected to the inverter output and the excess power is get injected to the grid. To have continuous power to the loads in industry, the grid is being used during non-sunshine periods.

Figure 4: Subsystem of the ANN based controller

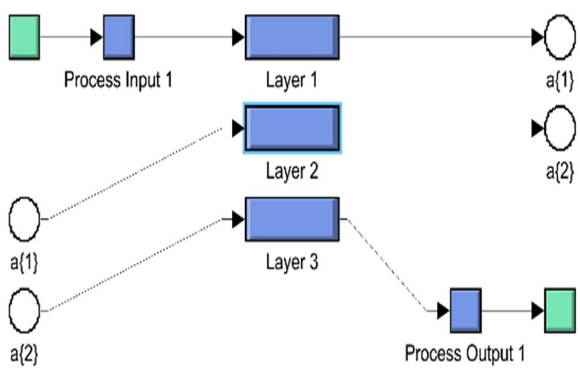
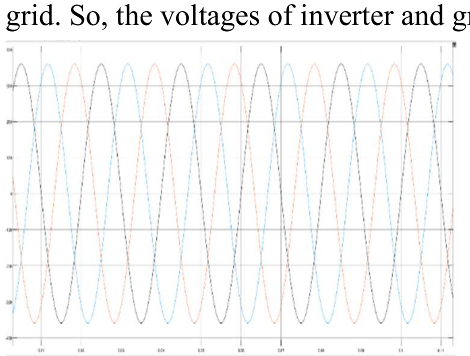


Figure 5: Hidden layers of an ANN

RESULTS:

The grid and inverter voltage are shown in the figure 6 and 7 respectively. The grid and inverter voltage which is the same value as 360 V and it is in three phase form and each of the phases shifted 120˚ from each other. Both of the voltages should be same for the integration of renewable energy to the electrical grid. So, the voltages of inverter and grid are same.



The figure 8 and 9 show the grid and inverter current respectively. As seen in previous comparison of inverter and grid voltages, here also the current should be same for both inverter and grid. Because, for the grid synchronization the current should also be same. Here, the value of the current of inverter and grid is around 17 A.

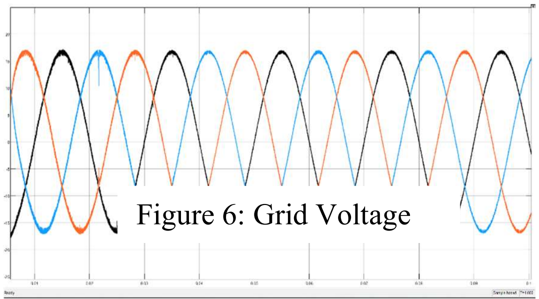


Figure 6: Grid Voltage

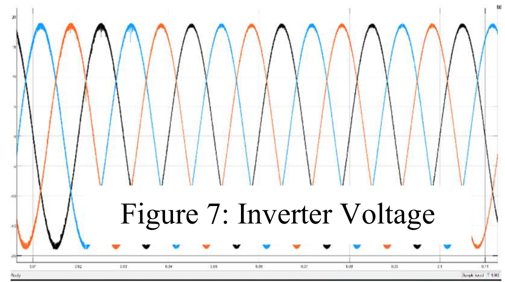


Figure 7: Inverter Voltage

The real power of the inverter and grid are shown in figure 10 and 11 respectively. The real power produced by the inverter is around 10 kW. The real power generated from the inverter is injected to the grid. Here, the grid real power is shown as -9 kW. Because, the power is get injected to the grid. The industrial load is connected across the 3-phase line, which consumes 1 kW power.

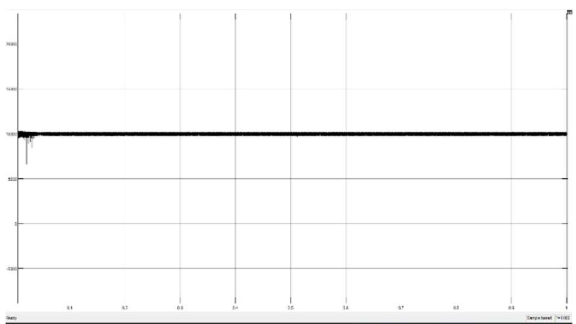


Figure 10: Real Power from the inverter

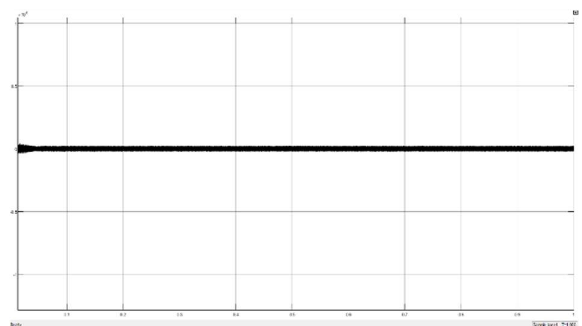


Figure 11: Real Power to the grid

T[illegible] are shown in fi[illegible] The reactive power is a 0 kVAR. The PV panel does not produce any reactive power. So, the reactive power of both the inverter and grid are 0 kVAR.

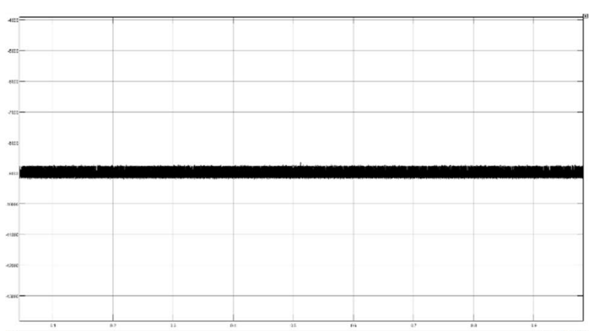


Figure 12: Reactive power to the grid

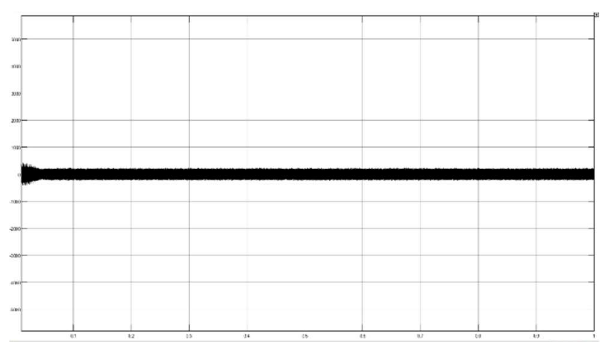


Figure 13: Reactive power from the inverter

CONCLUSION :

The work represents a substantial advancement in the integration of non-conventional energy sources into the already available power grid. Through the implementation of an Artificial Neural Network (ANN) control strategy, the system effectively addresses the inherent challenges associated with solar power generation, installed in rural industries such as variability in output and the need for reliable energy delivery. The successful integration of the SEPIC converter and three-phase inverter not only enhances voltage regulation and power conversion efficiency but also facilitates seamless synchronization with the grid. The ANN's ability to adaptively manage both real and reactive power output demonstrates its potential as a robust solution for improving grid stability and reliability. In conclusion, this work lays the groundwork for future research and development in the field of smart grid technology and renewable energy management. The findings and methodologies established can be further explored to enhance the scalability and robustness of similar systems.

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