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PV INTEGRATED BATTERY SYSTEM FOR POWER BALANCE IN MICROGRIDS USING ANN TECHNIQUE

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Abstract: In the process of electrifying each and every nook of the world and mitigating blackout issues that are becoming prominent, the stand-alone microgrids have their superiority. The proposed system presents the model to meet the power imbalances that are prominent in microgrids due to the intermittent availability of renewable sources that are used as distributed generation stand-alone microgrids.
In these systems, the balance between the generation and demand side has to be maintained at every instant. Due to the presence of power electronic and storage devices, there arises delay and harmonics, causing an imbalance that might exist for seconds yet deteriorate the system performance and damages. In this, a stand-alone microgrid with a PV system integrated with a Nickel-metal hydride battery is designed. To regulate the operation of the battery, the state of charge controlling with the open circuit voltage method (OCV) is employed. And the imbalances harmonics are mitigated by controlling the inverter with a PI controller and also artificial neural networks (ANN). It is observed that by introducing ANN, the harmonic distortion, rise time and overshoots have comparatively reduced by a considerable margin. The simulation results using MATLAB SIMULINK have been generated and presented.

Keywords: Power balance, PI controller, ANN, state of charge (SoC)

I.Introduction:

While it is impossible to imagine today's world without electric power, it is also a crucial concern how the power is being generated and what impact is being created on the globe during the process of energy conversion. The increasing global temperature and exhaustion of fossil fuels are alarming and forcing us to switch to clean and green energy generation. Therefore, renewable energy sources (RES) such as PV, wind, and tidal power generation are the alternatives. [14] 33% of the world's population in many developing countries yet don't have access to electricity. The grid interconnection and including all the areas which yet to be electrified is not a feasible task due to various factors such as geographical location and transmission line expenses. By considering these challenges, we arrived at the solutions such as distributed generation and utilizing as many renewable sources are available near the load location. Hence, Microgrids emergence has become the revolutionary substitute to mitigate the mentioned issues.
There are also other challenges like [16] blackouts are a major barrier to the continuous and reliable supply. In an interconnected grid, the blackouts are huge consideration because they would demand the entire shutdown of the system. Also in recent times, as per the news giants such as Forbes and CNBC, the blackouts have become enumerated and the US had to say 'Outages are the new norm.' "Microgrids with distributed generation and grid interconnection offer greater reliability and stability. But the stand-alone microgrids have higher scope

in electrifying inaccessible locations such as hilly terrains, forest areas, and tribal inhabited places. By utilizing the local energy sources, stand-alone microgrids are formed which are independent and don't get impacted by the blackouts. By ensuring enough backup, the continuity of the power supply comes into existence. Hence, this paper goes ahead with forming a microgrid with a PV array that is more reliable and accessible than the remaining RES.

Over the past few years, with extensive research and technology development in harnessing solar energy, the efficiency in the process of conversion into electrical energy has increased significantly and thus the cost of generation is reduced as well. In contrast to the remaining renewables, it is an undeniable actuality that Solar energy is less intermittent. The photovoltaic technology that is associated with solar energy is suitable to deliver even small loads and positions itself as a better alternative for the source in stand-alone microgrids. However, it is non-negotiable fact that there are power quality issues with the same, such as harmonics, voltage dropping, and phase imbalances. And one of the main causes behind these issues is power imbalances between generation and demand which happen due to the unpredictability of availability of sources and the existence of power electronic converters and power conditioning equipment.

To mitigate these barriers, an effective controller plays a crucial role. With the conventional PI controller, the task is accomplished easily yet there is always room for improvement. With the PI controller, though the steady-state error is implicitly reduced, the stability, the peak overshoot, and the various other parameters provide an opportunity to enhance the system's capability. For this reason, the well-ordered and coherent controller based on Artificial neural networks is chosen for the stand-alone microgrid to evaluate its performance, especially targeted to reduce the power imbalance between generation and demand. ANN algorithms are quick and give accurate results with their inherent attributes such as parallel processing and rigorous training process which continuously looks for the minute movements and acts to track the prerequired results.

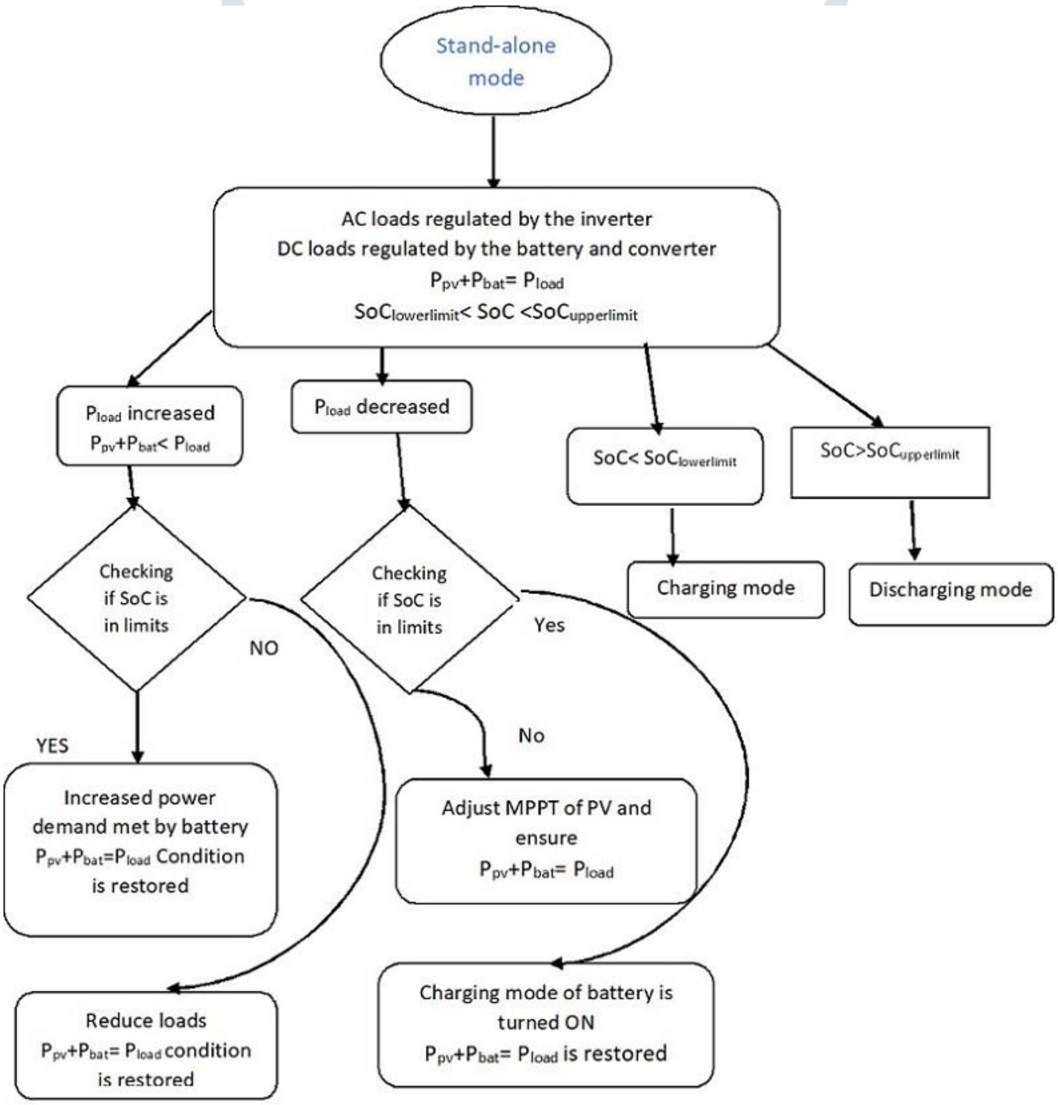

Figure 1: Flow chart explaining the operation

With the help of reputed journals and standardized websites, the study about microgrids has been done. "Challenges in Recent Microgrid Sytems: A Review" by Ashwini Kumar and Murari Lal Azad [16] has been

much help to understand the gap and barriers in expansion of microgrid technology. "Recent control techniques and management of AC microgrids: A critical review on issues, strategies, and future trends by Jaswant Singh and Surya Prakash Singh" [17] has given a strong objective for this project thesis by creating an overview of methods of managing microgrids, "Design And Simulation of a PV System with Battery Storage using Bidirectional DC-DC Converter using MATLAB Simulink" has helped to analyze the storage devices in the Microgrids. "Design and Simulation of a PV System Operating in Grid-Connected and Stand-Alone Modes for Areas of Daily Grid Blackout" [12] has given a clear analysis of blackouts in grids and the importance of having standalone grids. "Modeling and Simulation for an 8 kW Three-Phase Grid-Connected Photo-Voltaic Power System" [11] has helped in designing the components for the proposed model.
From the inputs taken from the literature survey, the proposed system has begun to be formed with the objective of mitigating the total harmonic distortion and eliminating the delay in a balance between power generation and demand. Firstly, the objective is to analyze the performance of the system with the PI controller and then compare the performance by employing ANN. The objective was to observe by what amount, the harmonics in the voltage waveform are reduced and try to eliminate any overshoots and, ensure a smooth transition while balancing the system.
With that being the objectives, the proposed model is designed in the simulation environment in the MATLAB SIMULINK. The basic operation of the system is explained in the flowchart figure1.
To give an overview of the system that was designed, the power balance equation plays an important role. The system is designed in such a way that, at any point in time, the power on the supply side equals the demand side.

$$P_{pv} + P_{bat} = P_{load}$$

Where, P_{pv} stands for Power generated from PV array; P_{bat} stands for power from the battery; P_{load} stands for the load on the demand side; SoC implies the state of charge which has upper and lower limits which are crucial parameters for the battery operation in charging and discharging mode.

With this basic operation of the model, the above objectives are tried to be achieved. The results for the same are generated and presented.

II. Problem Formulation:

A. Formation of a Microgrid with a PV array:

A technique known as photovoltaic (PV) uses semiconductors that exhibit the photovoltaic effect to convert solar energy into direct current electricity. Solar panels with several photovoltaic-containing cells are used to generate electricity using photovoltaic technology. With its versatility of usage and ability to set up the arrangement, PV arrays are gaining their popularity to be as DGs in the formation of Microgrids.
To form a PV array, we will start with the basic building block i.e, a PV or Solar cell. To model a PV cell, we need to consider the parameters such as saturation current, reverse saturation current, the current through a shunt resistor, photon current, and output current. And secondly, it is needed to obtain the data from the manufacturer's data sheet regarding the open circuit voltage, short circuit current, and voltage and current at maximum points. With this data, we will design a simple cell, whose combination in series and parallel would give the desired voltage as an output for the entire PV array.
The output of the PV array depends upon various factors, yet the most impacting factor is irradiance. The insolation is converted into current gain and the equivalent circuit of the solar cell is simulated.
Below figure2 is the equivalent diagram of the solar cell:

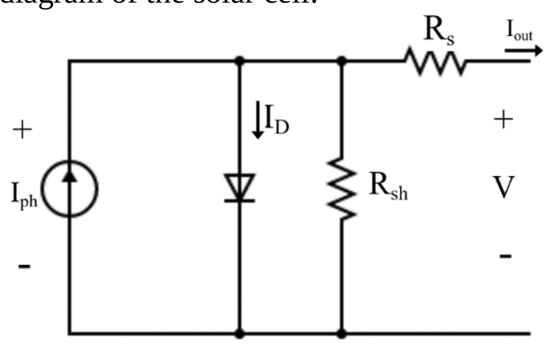

Figure 2: PV Cell equivalent diagram

The mathematical model of solar cells in series or parallel connection can be simply expressed as

$$I_{out} = I_{ph} - I_s [\exp(qV/BkT) - 1)]$$

$$I_{ph} - I_D = I_{out}$$

where I_{out} is output current of solar cell (A); V is output voltage of solar cell (Volts); I_s is reverse saturation current of solar cell; I_{ph} is the photon current; I_d is the diode current; q is quantity of electronic charge; k is boltzmann constant; B is ideal factor of solar cell; and T is solar cell surface temperature.
The appropriate selection of the shunt and series resistors is crucial. It depends on the circuit parameters which are obtained from the data sheet as per one's requirement. Any discrepancy while calculating these values would result in error in the output voltage.

B. Battery as a backup and its controller

Battery, an energy storage is a crucial part in the microgrids which employ renewable sources as distributed generation sources. As RES are intermittent in nature, a backup is always necessary to ensure continuous supply existence. Therefore, utmost care is taken in calculating the backup required.
The first step in calculating battery is estimating daily usage. Then calculate the hours for which backup is required i.e, the solar energy is unavailable. Then a rating of battery is decided. Based on the depth of discharge, efficiency, and effects of temperature characteristics, a battery is selected. In this case Ni-metal hydride battery is selected.

Battery Storage = Total Load * Backup Time

No. of batteries required = Required battery storage/battery capacity

With the battery, the DC-DC converter and Inverter are placed to supply DC and AC loads respectively. To regulate the charging and discharging cycles of the battery, state of charge controlling is implemented. To implement this, the method of open circuit voltage is employed. Whenever load increases or solar panel's irradiation decreases, the voltage level falls. Then the battery turns into discharging mode by supplying to the load. When SoC (state of charge) is less than the lower limit, the battery turns ON into charging mode. This implementation is can be done by evaluating a transfer function into block diagram and simulating it. The following diagram shows the SoC implementation of battery storage. Fig.3[9]

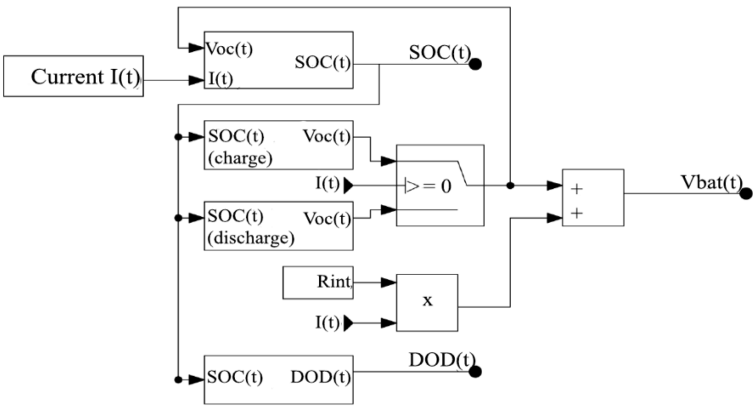

Figure 3: State of Charge implementation

C. DC-DC converter and Inverter:

To supply to the DC loads, a DC-DC boost converter is employed. The voltage is boosted and supplied to the loads to mitigate any voltage reductions caused in the intermediate stages. While constructing the boost converter, IGBTs are employed as switching devices for their superior switching properties. The design considerations of boost converter are the selection of inductor and capacitor. Based on the load current required and output voltage, these calculations are made from the equations obtained by the operation of the converter. The inverter part design mainly involves pulse width modulation (PWM). The pulses to the inverter vary the performance and the inverter efficiency. The output voltage of the inverter will have harmonics that lead to an imbalance in power curves. So, in this paper, PI controller is employed in PWM generation and the performance is compared with ANN (artificial neural networks) as well. In this model, a three-phase, six pulse inverter with IGBTs is utilised. The pulse generation model is designed and the total harmonic distortion is calculated for the voltage waveform. [11]

D. PI controller:

The controller attempts to correct the error between a measured process variable and desired setpoint by calculating the difference and then performing a corrective action to adjust the process accordingly. PI controller is a variation of PID controller which is most extensively used. The two tuning values for a PI controller are the controller gain, K_c and the integral time constant τ_I. The value of K_c is a multiplier on the proportional error and integral term and a higher value makes the controller more aggressive at responding to errors away from the set point. The set point (*SP*) is the target value and process variable (*PV*) is the measured value that may deviate from the desired value. The error from the set point is the difference between the *SP* and *PV* and is defined as e(t)=SP-PV.

Digital controllers are implemented with discrete sampling periods and a discrete form of the PI equation is needed to approximate the integral of the error. This modification replaces the continuous form of the integral with a summation of the error and uses Δt as the time between sampling instances and n_t as the number of sampling instances. Such a discrete controller is shown in the figure 4.

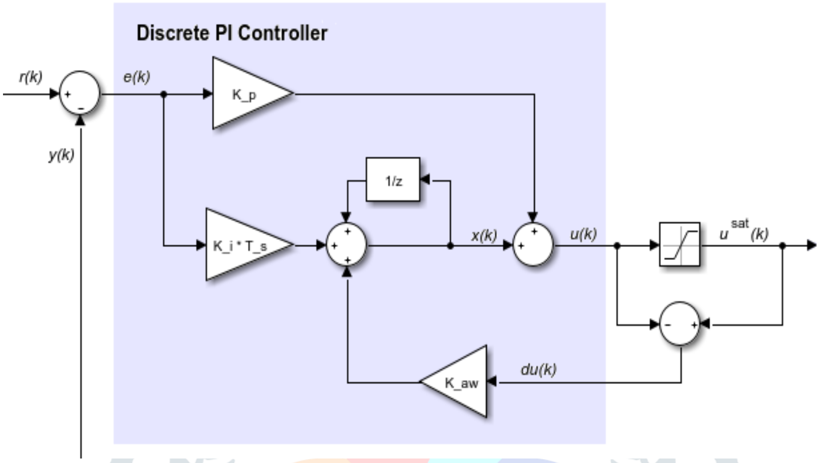

Figure 4: Discrete PI controller

Where,
$u(k)=[K_p+(K_i+du(k)\,K_{aw})\,T_s\,Z\,(z-1)^{-1}]\,e(k)$,

- u is the control signal.
- K_p is the proportional gain coefficient.
- K_i is the integral gain coefficient.
- K_{aw} is the anti-windup gain coefficient.
- T_s is the sampling period.
- e is the error signal.

While we cannot directly select the K_p (proportional constant) and K_I (integral contant) parameters because we don't have the numbers for the transfer function of the system, we can still get 99% of the way by knowing what system equation transfer function we want. [4]
Requirements:

1. Overshoot Less than 10%
2. Rise time of 2 seconds or less

With these requirements in the mind, we go ahead to design the PI controller by firstly designing the transfer function. We can accurately design this sort of system with a third-order transfer function. It consists of a dominant pole second order system and a non-dominant pole first order system.
It should look like this:

$$\frac{1}{(s^2+2\omega n\zeta * s+\omega n^2)\,(s+\alpha)}$$

The overshoot is controlled by the damping coefficient which is a number between (0 and 1). Setting these values is not easy. The process of selecting a controller parameter to meet a given performance specification is known as controller tuning. Ziegler and Nichols suggested rules for tuning PI controller (mean to set the values of K_p and K_i) based on the experimental step response or based on the value of K_p that result is marginal stability. These rules can, of course, be applied to the design of system with known mathematical models. Such rules suggest a set of values of K_p and K_i that will give a stable operation of the system. However, the resulting system may exhibit a large maximum overshoot in step response, which is unacceptable. In such a case, we need a series of fine tunings until an acceptable result is obtained. In fact, the Ziegler-Nichols tuning rules give

an educated guess for parameter values and provide a starting point for fine-tuning, greater than giving the final settings for K_p and K_i in a single shot.
Below is the figure depicting how a PI controller is implemented in Simulink environment.

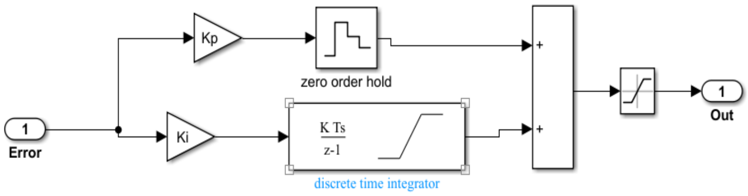

Figure 5: PI controller in Simulink

Zero hold out converts an input signal with a continuous sample time to an output signal with a discrete sample time we specify. This helps in making a PI controller in discrete mode. We use the discrete-time tntegrator block in place of the Integrator block to create a purely discrete model. These parameters help us to tune the PI controller with minute sampling periods as well so that we get desired output accurately.

E. Artificial Neural Networks:

An artificial neural network (ANN), often just called a "neural network" (NN), is a mathematical model or computational model based on biological neural networks. In more practical terms neural networks are non-linear statistical modeling tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. To fulfil our objectives, among the several types of artificial neural networks, a feed forward network is chosen with a backpropagation algorithm. [8]
In the below figure, the functioning of a feed forward network is explained.

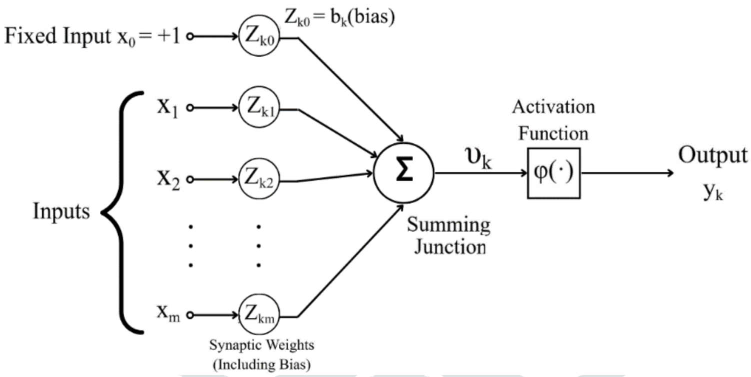

Figure 6: Neural network operation

Where,
$x_1, x_2 \ldots\ldots x_m$ are the m inputs.
$Z_{k1}, Z_{k2} \ldots. Z_{km}$ are weights attached to the input links.
For the above model,

$$Uk = \sum_{j=1}^{m}(Zkj\ \ Xj)$$

$$Vk = Uk + bk$$

The bias bk has the effect of increasing or lowering the input of the activation function.

$$yk = \varphi(Uk + bk)$$

The Backpropagation algorithm looks for the minimum value of the error function in weight space using a technique called the delta rule or gradient descent. The weights that minimize the error function is then considered to be a solution to the problem. The following steps are followed in this algorithm, which are mentioned related to the figure 7.

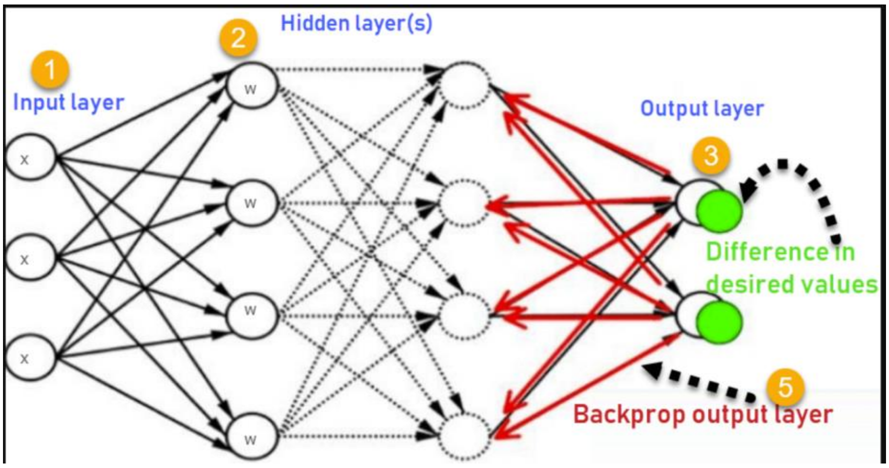

Figure 7: Back propagation algorithm

(i) X enters the preconnected path as an input.
(ii) Real weights W are used to model the input. Typically, weights are chosen at random.
(iii) Determine each neuron's output from the input layer via the hidden layers to the output layer.
(iv) To change the weights such that the error is reduced, go back from the output layer to the hidden layer.
(v) Repeat the procedure until the desired results are obtained.

The implementation of ANN in this model comprises of one input layer and one output layer along with one hidden layer. The network's complexity can be increased with the increasing number of layers which also gives better results. Once a network has been structured for a particular application, that network is ready to be trained. To start this process the initial weights are chosen randomly. Then, the training, or learning, begins. The method of supervised training is employed in this model. In supervised training, both the inputs and the outputs are provided. The network then processes the inputs and compares its resulting outputs against the desired outputs. Errors are then propagated back through the system, causing the system to adjust the weights are continually tweaked. The set of data which enables the training is called the "training set". During the training of a network the same set of data is processed many times as the connection weights are ever refined. [10]

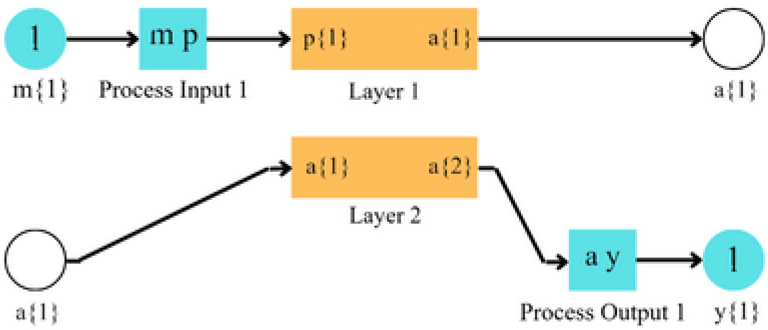

Figure 8: Layers in neural networks

The output voltage is refined with ANN in our system. Since the power is a product of voltage and current, by refining voltage, the imbalances and harmonics are reduced. Also, the quick action and accurate training of ANN help in reducing rise time and peak overshoots in the power curves. Thus, the inverter action is improved by employing ANN for its PWM pulse generator.

III. Simulation for proposed model and results:

To implement the main idea that was described all along, and to observe the results of the system, we have chosen the simulation environment as MATLAB SIMULINK. In the PV system modelling, using the insolation to current source converter gain block, we designed the solar panels with appropriate internal and shunt resistances as per the required open circuit voltage and short circuit current. The PV system is interfaced with the battery system as well as the inverter to supply to AC loads. The power from the solar that is rejected by the loads or the grid is fed into the battery and stored. This balance is always ensured in the system with the controllers employed. For the battery system, a controller based on the State of charge (OCV method) is implemented to dictate when the battery must be turned ON and OFF. This entire controlling method is achieved by simulating the block diagram resulted from the transfer function obtained by the state equations. The battery system is also interfaced with DC-DC converter to supply to DC loads if existing and also, we operate it in Boost converter configuration to compensate for the losses in the system. The inverter existing in the system converts the dc power into ac power to supply to the AC loads. The operation i.e., switching frequency of the inverter is commanded by discrete PI controller conventionally. Also, in this system, it is observed by implementing the Artificial Neural Networks. The gate pulses to the IGBTs in the three-phase inverter are instructed by these controlling techniques. The results and observations made in this process are mentioned ahead. This controller part is a crucial in this system. It includes the calculation of discrete RMS values of the phase voltages and currents and constructing a PLL (Phase locked loop) for the synchronization of the frequencies with the loads which usually be operating at the fixed frequency for the efficient operation. The other important aspect is that, inverter being a power electronic equipment, introduces a large number of harmonics into the system which would make the quality of power deteriorated. So, these controllers would be directed to reduce the harmonics and thus improve the efficiency of the system and improve the quality of power. The differences and improvements due to usage of various controllers is shown. Also, the system has a passive filter placed right ahead the loads to filter out the harmonics and ripple content to the most. The various models existing out there are designed with various configurations of passive elements such as resistor, inductor and capacitor. By preferring LCL filter over LC filter, the results are generated and the same is being presented. The loads which are chosen are non-linear. Practically, the loads possess some non-linear nature though it be domestic or industrial.

The results in this paper are obtained for three aspects and the analysis and observations are done based on the waveforms obtained. The outputs of the PV array such as solar power and voltage are shown. Similarly for battery and inverter, the output voltage waveforms are shown.

The three sections of the results are:

1. PI controller with LC filter
2. PI controller with LCL filter
3. ANN with LCL filter

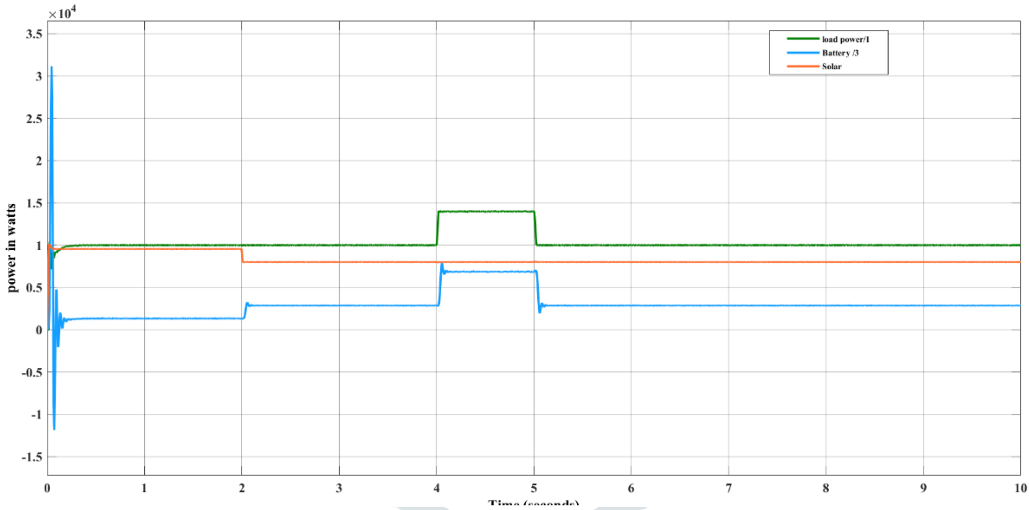

Figure 9: Power balance using PI controller and LC filter

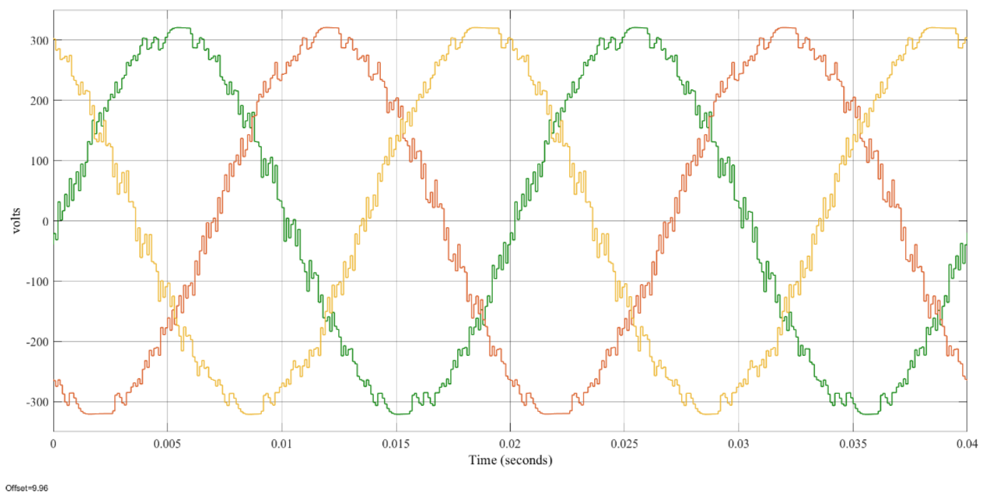

Figure 10: Output voltage with PI controller and LC filter

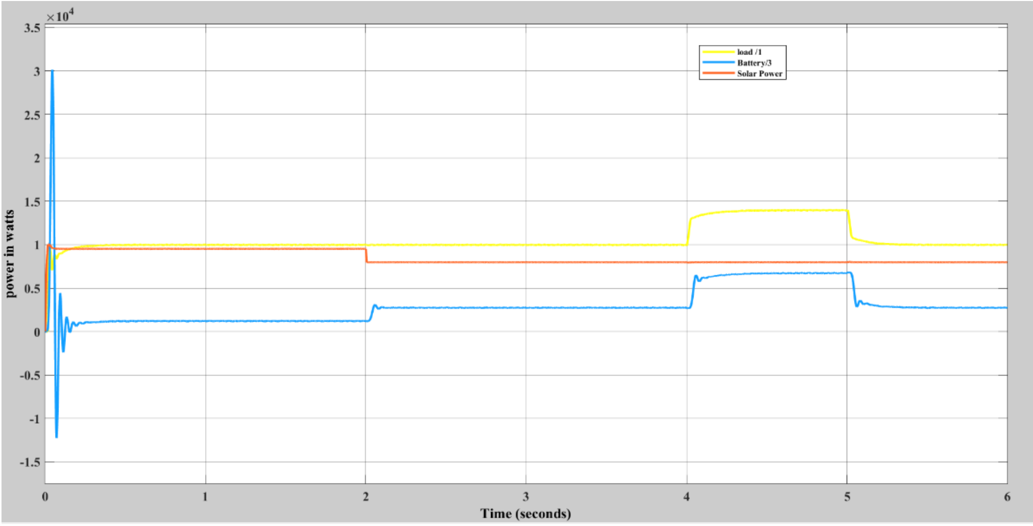

Figure 11: Power balance using PI controller and LCL filter

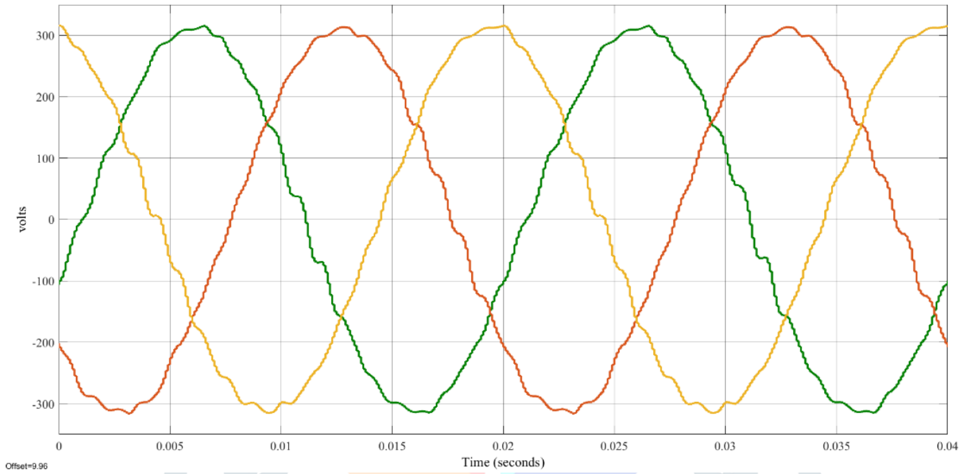

Figure 12: output voltage with PI controller with LCL filter

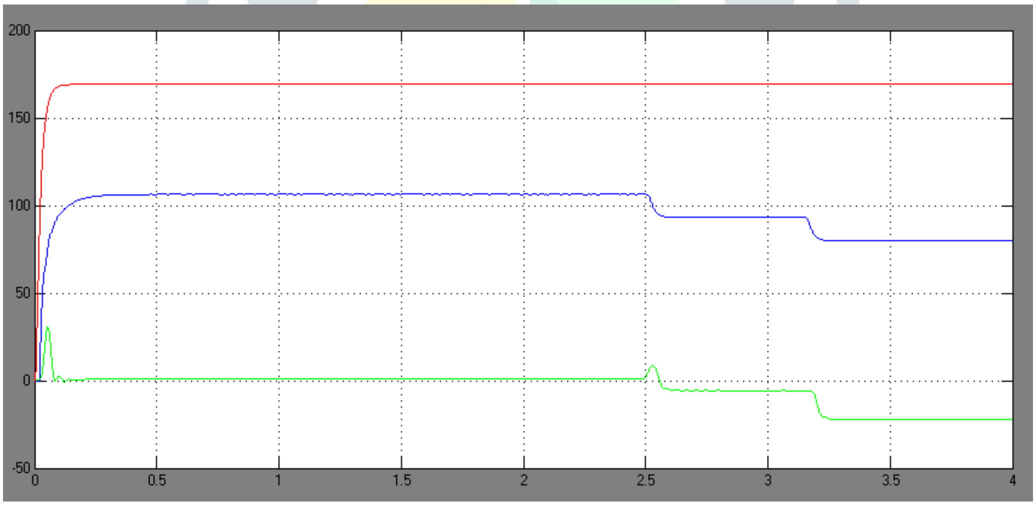
Figure 13: Power balance using ANN and LCL filter

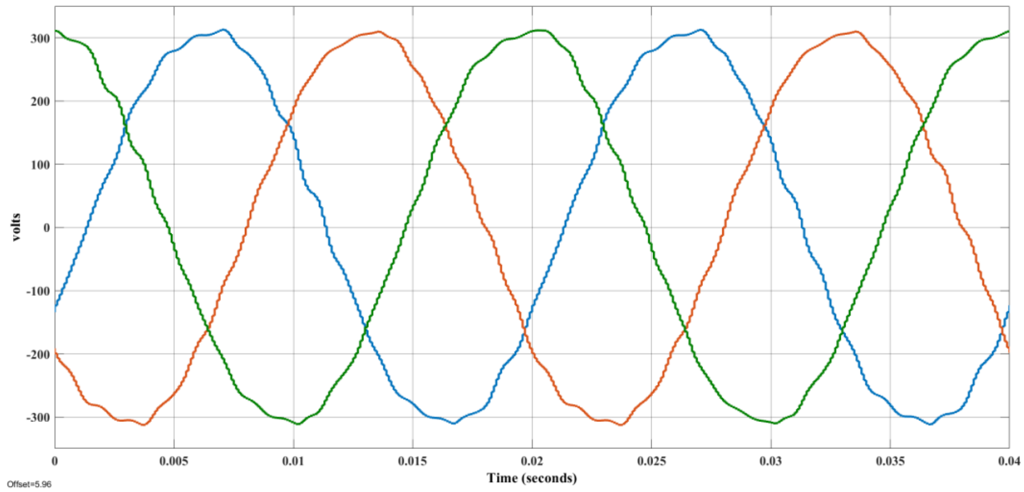

Figure 14: Output voltage using ANN and LCL filter

IV. Observations:

The PI controller has been the conventional controller for many applications since centuries for its excellent tuning properties and ability to improve the performance of the system by a great margin. However, there is an exponential growth in the increment of usage of non-linear loads in the world.
With the arrival of smartness in to the devices that are connected to the grid and also the importance to make the power supply smarter and more automated, the usage of power electronics i.e, semi-conductor devices have increased. With this non-linearity being increasing, there's always a need to improve the performance of the existing controllers and upgrade the system. Smartness being introduced, it is high time that we look for smart controllers as well. And that introduces the story of Artificial neural networks to eradicate the harmonics with utmost efficiency.
In this system, based on the results that are generated on three categories, the observations will be listed the same.
When the PI controller is existing in the system, the power imbalance occurred due to the sudden surge and variation in the load is met obviously but with a peak overshoot and undershoots occurring first. This can be seen in the load waveforms. Also, upon observing the voltage and current waveforms, the total harmonic distortion is found to be 26%. This analysis is done upon using LC filter.
When the same configuration is replaced with the LCL filter which is more efficient in removing the harmonics, there isn't much difference seen in load power waveforms. The harmonics in the voltage and current waveforms are improved with the THD content of 19.38%. But while meeting the power imbalance that is being caused in the system, there is no much improvement in mitigating the overshoots and undershoots.
By replacing the PI controller, with the artificial neural networks (ANN), it is observed that the harmonics content in the voltage waveforms has considerably by making THD as 3.221%.
Also, the power imbalance was met as efficiently as possible with minimal rise time and overshoots. With ANN, the overall performance has improved by its ability to reduce the errors as effective as possible.

V. Conclusion and Scope*:*

This paper is being presented on the base topic of challenges in implementing microgrids which are crucial part of the electrifying and digitalizing the world. One of the challenges i.e., power imbalances being the main objective of the project, a model is proposed with PV system with battery as generating source and storage device respectively. By employing, PI controller to control the pulses of Inverter, the system is simulated and performance is analysed. Replacing the PI controller, the performance of the system is analysed by implementing artificial neural networks (ANN).
By the simulation results that are generated, it is concluded that, ANN gives a better performance in mitigating the harmonic distortion and ensures the smooth transistion in balancing the power generation and load demand.
The advancements can be made for the proposed model by analysing the system with load modelling. By selecting special devices or sensitive devices, modelling them and analysing the effect on them can be a great way to expand and improvise the system performance and reliability.
Also, by employing numerous distributed generation sources and integrating them, the system's performance can be analysed with ANN. And by increasing the layers of the neural network, the system performance can be improved.

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