A NEW MODIFIED ARTIFICIAL NEURAL NETWORK BASED MPPT CONTROLLER FOR 
THE IMPROVED PERFORMANCE OF AN ASYNCHRONOUS MOTOR DRIVE

1B. Pakkiraiah and 2G. Durga Sukumar

1Department of Electrical and Electronics Engineering, 2Vigna’s Foundation for Science Technology and Research University, 1,2Guntur, A.P, India-522213.

ABSTRACT
Solar energy is an important alternative out of the various renewable energy sources. On an average the sunshine hour in India is about 6hrs per day also the sun shines in India is about 9 months in a year. To generate electricity from the sun, the solar photovoltaic (SPV) modules are used. The SPV comes in various power outputs to meet the load requirements. Maximization of power from a solar photo voltaic module is a special case to increase the efficiency of the PV system. The artificial neural network (ANN) based maximum power point tracking (MPPT) controller is used to track the maximum power. DC-DC boost converter and space vector modulation based inverter are used to provide the required supply to the load. The proposed ANN based MPPT improves the system efficiency even at abnormal weather conditions. Here a lot of improvement in torque and current ripple contents is obtained with the help of ANN based MPPT for an asynchronous motor drive. Also the better performance of an asynchronous motor drive is analyzed with the comparison of conventional and proposed MPPT controller using Matlab-simulation results. Practical validations are also carried out and tabulated.

Keywords- solar photovoltaic (SPV) system, artificial neural network (ANN), maximum power point tracking (MPPT) controller, DC-DC boost converter, Space vector modulation (SVM), Asynchronous motor (ASM) drive, Torque and ripple.

I. INTRODUCTION
As the earth natural resources decreasing day by day, to meet the increase in the power demand the power sector is looking at alternate energy resources. Due to usage of renewable energy sources the carbon content in the atmosphere can be reduced by which global warming problem can be overcome. Out of various renewable sources solar PV System is leading now a day due to its simple structure. The various structure of PV panel system and their suitability for locations have discussed [1-3]. The efficiency of the PV system can be increased by using power electronic devices along with maximum power point controller.

Several algorithms are developed to track the maximum power point efficiently. Most of the existing MPPT algorithms suffer from the drawbacks of being slow tracking, wrong tracking and oscillations during rapidly changing weather conditions. Due to this the utilization efficiency is reduced. To overcome this, an ANN based MPPT is implemented. Here two stage MPPT is implemented to improve non uniform irradiance on the PV modules. A blocking diode is connected in series to PV string to prevent reverse current flow from load, a bypass diode is also used to improve the power capture and also to the prevent hotspots [4]. ANN based MPPT with 2 stage method for MPP presents the independent of time dependency and trade property, due to this MPP can be tracked without time increment through PV characteristic changes [5]. The nonlinear characteristics of array with rapidly changing irradiation and temperature can be overcome using differential Evolution (DE) and ANN along with conventional MPPT [6].

A new ANN based MPPT algorithm is introduced by using the traditional Incremental Conductance method using sensors to get better performance. Compared to Incremental Conductance and the P&O controller it is much faster for the sudden change of the weather combinations. To evaluate the effectiveness of the training network the mean square error is introduced to give accuracy of the network [7]. The 2-level neural network-genetic algorithm is used to estimate the battery power influencing factors as light intensity, temperature and battery junction temperature [8]. A recurrent neural network model is trained by a Particle Swarm Optimization (PSO) method for solar radiation monitoring and controlling to predict the accurate solar radiation of standalone systems of hybrid power systems [9].

3 layered ANN with back propagation based MPPT is implemented for boost converter of standalone PV system to minimize the long term system losses and to increase the conversion efficiency even under variable temperature [10]. PV module energy conversion efficiency lies in between 12%-20%. The energy conversion loss depends on PV system and also the loads that are connected. This can be overcome using MPPT with DC-DC converter to get the required load voltage at the maximum power point voltage. [11-12]. Solar energy is a vital untapped resource in a tropical country like ours. India plans to produce 20 Giga watts of solar by 2020. A MPPT controller with the inverter is connected to the asynchronous motor drive with space vector modulation technique to get the better performance with the PV system. Various strategies are used for selecting the order of vectors with zero vectors to reduce the harmonic content and the switching losses [13-14].

The space vector modulation diagram of an inverter is composed of number of sub hexagons. The sector identification can be done by determining the triangle, which encloses the tip of the reference space vector diagram with forming of six regions [15-16]. To overcome the distortions in the output voltage and currents of an inverter, the single phase SVM based cascaded H-Bridge multilevel inverter is used for PV system to improve the quality of power even under abnormal weather conditions. The better torque ripple and the performance is obtained with the help of genetic algorithm-particle swarm optimization based
indirect vector control for optimal torque control of an induction motor drive [17]. A comparison of neuro fuzzy based space vector modulation with neural network work and conventional based system has been presented [18].

The advantage of this proposed ANN based MPPT algorithm is to control the MPP even under abnormal weather conditions, compared to other conventional algorithms. In section 2 mathematical modeling of PV array is discussed. Section 3 explains about the proposed MPPT algorithm. Mathematical modeling of asynchronous motor drive is discussed in section 4. Section 5 states a brief note on proposed space vector modulation technique. Using the proposed MPPT along with DC-DC converter to boost up the PV output and to feed asynchronous motor drive is detected in section 6. Matlab-simulation results with the comparison of conventional and proposed MPPT techniques are presented in section 7. The concluding remarks are stated in section 8.

II. MATHEMATICAL MODELING OF PV ARRAY

Solar PV system is made of photovoltaic cells. Cells are grouped to form panels and panels are grouped to form array. The basic mathematical equations describes the ideal PV cell and those are clearly mentioned in equations (1) and (2)

\[ I_{PVCell} = I_{PVCell} - I_{0Cell} \left( \frac{V_{PVCell}}{kT} \right) - 1 \]

Where:

- \( I_{PVCell} \) is the diode reverse saturation current, \( I_{0Cell} \) is the diode reverse saturation current, \( V_{PVCell} \) is the voltage across the PV cell.

![Practical PV cell equivalent circuit](image)

PV system basic equation does not represent I-V characteristics, as a practical PV module consists of various PV cells which require additional parametric values as series and parallel resistances (\( R_{Ser} \) & \( R_{Shi} \)) which are represented in Fig. 1. PV module modeling is based on mathematical equation of the solar cell which is given by Eq. 2

\[ I_{CELL} = I_{PVCell} - I_{0Cell} \left( \frac{V_{PVCell}}{kT} \right) - 1 \]

Where:

- \( I_{MD} \) = PV module current in Amps
- \( I_{PVCell} \) = Photocurrent or light generated current in Amps
- \( I_{0Cell} \) = Reverse saturation current of a diode in Amps
- \( Q \) = Electron charge in Coulombs
- \( N \) = Ideality factor (taken from data sheet)
- \( k \) = Boltzmann constant in J/K
- \( T_{APP} \) = Applied temperature for the PV module in Kelvin
- \( V_{MD} \) = Module voltage in Volts
- \( R_{Ser} \) = Series resistance in ohms
- \( R_{Shi} \) = Parallel resistance in ohms

Current generated by light \( (I_{PVCell}) \) depends linearly on solar radiation and also on temperature is defined by Eq. (3)

\[ I_{PVCell} = \frac{P_{APP} \times V_{REF}}{Q} \times \frac{I_{REF}}{I_{PVCell}} \]

Where:

- \( P_{APP} \) = Applied solar irradiance in W/m² (applied to the module during the experiment)
- \( P_{REF} \) = Reference irradiance in W/m² (1000 W/m² is taken under STC)
- \( I_{REF} \) = Module short circuit current (taken from the data sheet)
- \( T_{APP} \) and \( T_{REF} \) are applied and reference temperatures in Kelvin

| Irradiance (W/m²) | Temperature (in °C) | \( T_{SC} \) (°C) |
|-------------------|--------------------|-----------------|
| 1000              | 25 °C              | 2.18            |
| 800               | 30 °C              | 2.18            |
| 500               | 40 °C              | 2.18            |
| 250               | 50 °C              | 2.18            |
| 100               | 60 °C              | 2.18            |
| 50                |                    |                 |

Modules reverse saturation current \( (I_{RS}) \) at nominal condition and reference temperature is given by Eq. (4)

\[ I_{RS} = \frac{E_{GO}}{q} \times \left( \frac{I_{RS}}{I_{PVCell}} \right)^{1/N} \]

Where:

- \( I_{RS} \) = Reverse saturation current in Amps
- \( N_{T} \) = total no. of cells in a module

Here module voltage decreases as the applied temperature goes on increases which can be calculated by Eq. (5)

\[ V_{MD} = \frac{P_{APP} \times V_{REF}}{Q} \times \ln\left( \frac{I_{PVCell} \times I_{0Cell}}{I_{RS}} \right) \]

On the other hand saturation current \( (I_{Sat}) \) is given as

\[ I_{Sat} = I_{RS} \times \left( \frac{E_{GO}}{kT_{APP}} \right)^{2} \times \exp\left( \frac{E_{GO}}{kT_{APP}} - \frac{1}{T_{APP}} \right) \]

Where:

- \( E_{GO} \) = is the semiconductor band gap energy of the module in J/C

The shunt resistance \( R_{Shi} \) is inversely proportional to leakage current and a small variation of series
resistance will affect the PV output power. A PV cell will produce less than 2 watts at approximately 0.5 V and 0.7 V at open circuit condition. The cells must be connected in series and parallel to get required power. Array basic output current of single diode module is calculated by Eq. (7)

$$I_{PM} = \frac{I_{sc}}{N_{s}} - \frac{V_{oc}}{N_{p}}$$

Where $N_{s}$ and $N_{p}$ are the number of solar cells connected in series and parallel. Modeling of PV array is done based on data sheet parameters of SSI-3M6-250W poly-crystalline solar module at 25° C and 1000 W/m². Based on above parameters PV model in Simulink is developed under standard test conditions.

III. PROPOSED MAXIMUM POWER POINT TRACKING ALGORITHM

Maximum power point tracking control technique is used mainly to extract maximum capable power of the PV modules with respective solar irradiance and temperature at particular instant of time by Maximum Power Point Tracking Controller. A number of algorithms were developed to track the maximum power point efficiently. Most of the existing MPPT algorithms suffer from the drawbacks of slow tracking, wrong tracking and oscillations during rapidly changing weather conditions. Due to which the utilization efficiency is reduced.

To overcome these drawbacks an ANN based MPPT Control technique is introduced in this paper. Here it improves the performance of the system and efficiency with much better than any other conventional methods. In this technique a multi layered neural network is used. A two-stage off-line trained artificial neural network based MPPT is added to estimate the temperature & irradiance levels from the PV array voltage and current signals.

Supervised learning is implemented to nullify the error with providing the required multiplication factors to the weights at the hidden layer. This technique gives the better performance even under rapidly changing environmental conditions for both steady and transient instants with reducing the training set. The boost converter, inverter are used to provide maximum output voltage to the load. Here a supervised learning feed forward trained network is introduced to overcome the non-linearities of PV array. Proposed artificial neural network based MPPT algorithm flow chart is shown in the Fig. 2

Fig 2. ANN based MPPT

a. Practical Outputs of Conventional MPPT Controller with Variable Irradiance and Constant Temperature

When the irradiance varies from 100, 250, 500, 800 and 1000 W/m² it is observed that the PV current and voltage will increases with irradiance levels. Due to this net PV array power also gets increases. These characteristics are observed in Fig. 3

Fig 3. Practical I-V & P-V characteristics with variable irradiance and constant temperature

b. Practical Outputs of Conventional MPPT Controller with Variable Temperature and Constant Irradiance

When the temperature varies from 20° C, 30° C, 40° C, 50° C and 60° C it increases the PV current marginally with drastically decrease in PV array voltage. Due to this net PV array output power reduces. These characteristics are presented in Fig. 4

Fig 4. Practical I-V & P-V characteristics with variable temperature and constant irradiance

c. Practical Outputs of Proposed MPPT Controller with Variable Temperature and Variable Irradiance

When both the temperature and irradiance are variable then it increases the PV module current and decreases the voltage till the temperature rise and vice-versa. Also it increases the array current and slightly
increases the voltage till the irradiance rise and vice-versa. These results are illustrated in Fig. 5.

IV. MATHEMATICAL MODELING OF ASYNCHRONOUS MOTOR DRIVE

The mathematical modeling of a three-phase, squirrel-cage asynchronous motor drive can be described with stationary reference frame as

\begin{align}
V_{ds} &= (R_s + 2L_s)I_{ds} + P L_d I_{qs} \\
V_{qs} &= (R_s + 2L_s)I_{qs} + P L_q I_{ds} \\
0 &= v_d - \omega_s - \tau_d + \tau_{ds} \\
0 &= v_q - \omega_s - \tau_q + \tau_{qs}
\end{align}

(8)-(11)

Where \( \omega_d = \frac{2\pi}{60} \cdot p \).

Suffixes S and R represents stator and rotor respectively. \( V_{ds} \) and \( V_{qs} \) are d-q axis stator voltages respectively, \( i_{ds} \), \( i_{qs} \) and \( i_{dR} \), \( i_{qR} \) are d-q axis stator currents and rotor currents respectively. \( R_s \) and \( R_R \) are stator and rotor resistances per phase. \( L_s \), \( L_R \) are self-inductances of stator and rotor and \( L_m \) is mutual inductance. Stator and rotor flux linkages can be expressed as

\begin{align}
\lambda_{ds} &= L_s i_d + L_{ms} \theta_d \\
\lambda_{qs} &= L_s i_q + L_{ms} \theta_q \\
\lambda_{dR} &= L_R i_d + L_m \theta_d \\
\lambda_{qR} &= L_R i_q + L_m \theta_q
\end{align}

(12)-(15)

From the above equations (8)-(11), Squirrel-cage asynchronous motor can described by following equations in stator reference frame as

\begin{align}
\frac{d\theta_d}{dt} &= \frac{v_d}{L_s} - \frac{\lambda_{ds}}{L_s} \\
\frac{d\theta_q}{dt} &= \frac{v_q}{L_s} - \frac{\lambda_{qs}}{L_s} \\
\frac{d\theta_d}{dt} &= \frac{v_d}{L_s} - \frac{\lambda_{dR}}{L_R} \\
\frac{d\theta_q}{dt} &= \frac{v_q}{L_s} - \frac{\lambda_{qR}}{L_R}
\end{align}

The electromagnetic torque \( T_e \) of the induction motor is given by

\begin{align}
T_e &= \frac{3}{2} (\lambda_{ds} i_q - \lambda_{qs} i_d)
\end{align}

(16)

(17) described in the previous section and putting \( \lambda_{qR} = 0 \), the electromagnetic torque of the motor in the vector control can be expressed as

\begin{align}
T_e &= \frac{3}{2} (\lambda_{ds} i_q - \lambda_{qs} i_d) \\
\lambda_{ds} &= \frac{\lambda_{dR} - \lambda_{qR}}{L_s - L_R}
\end{align}

(18)

(19)

If the rotor flux linkage \( \lambda_{dR} \) is not disturbed, the torque can be independently controlled by adjusting the stator \( q \)-axis component current \( i_{qs} \). As the rotor flux aligned on \( d \)-axis, this leads to \( \lambda_{qR} = 0 \) and \( \lambda_{dR} = \lambda_{qR} \), then

\begin{align}
\omega_s &= \frac{3}{2} \frac{v_d}{\lambda_{dR}} - \frac{v_q}{\lambda_{qR}}
\end{align}

V. PROPOSED SVM TECHNIQUE FOR TWO-LEVEL INVERTER

In this the space vector modulation algorithm for two level inverter is introduced for which the solar panels are connected to provide the dc supply. SVM basic principle and switching sequence is given in order to get symmetrical algorithm pulses and voltage balancing. This scheme is used to control the output voltage of the two level inverter with the ANN based MPPT controller. In the SVM algorithm, the \( d \)-axis and \( q \)-axis voltages are converted into three-phase instantaneous reference voltages. Then the imaginary switching time period proportional to the instantaneous values of the reference phase voltages. Which are defined as

\begin{align}
T_{d} &= \left( \frac{2\pi}{60} \right) \frac{V_{dS}}{V_{ds}} \\
T_{q} &= \left( \frac{2\pi}{60} \right) \frac{V_{qS}}{V_{qs}}
\end{align}

(20)

Where \( T_d \) and \( V_{ds} \) are the sampling interval time and dc link voltage respectively. Here the sampling frequency is the twice the carrier frequency.

Then the maximum (MAX), middle (MID) and minimum (MIN) imaginary switching times can be in each sampling interval by using (21)-(23)

\begin{align}
T_{MAX} &= MAX(T_{dS}, T_{qS}, T_{UL}) \\
T_{MIN} &= MIN(T_{dS}, T_{qS}, T_{UL}) \\
T_{MID} &= MID(T_{dS}, T_{qS}, T_{UL})
\end{align}

(21)-(23)

The active voltage vector switching times \( T_1 \) and \( T_2 \) are calculated as

\begin{align}
T_1 &= T_{MAX} - T_{MID} \text{ and } T_2 &= T_{MID} - T_{MIN}
\end{align}

(24)

The zero voltage vectors switching time is calculated as

\begin{align}
T_0 &= T_1 - T_2
\end{align}

(25)

The zero state time will be shared between two zero states as \( T_0 \) for \( T_0 \) and \( T_f \) for \( T_f \) respectively, and can be expressed as

\begin{align}
T_0 &= K_0 T_f \\
T_f &= (1 - K_0) T_f
\end{align}

(26)-(27)

The various SVM algorithms can be generated by changing \( K_0 \) between zero and one. However, in this SVM algorithm, the zero voltage vector time distributed equally among \( V_0 \) and \( V_f \) as shown in Fig. 6. Hence, here \( K_0 \) is taken as 0.5 to obtain the SVM algorithm.
VI. PROPOSED MPPT SYSTEM WITH DC-DC CONVERTER, INVERTER AND ASM DRIVE

The below system represents the proposed system structure with DC-DC converter. In this, PV array contains 6 PV modules with 250 Watts each; these modules are connected in series and parallel to yield better output voltage and current. The proposed artificial neural network (ANN) based MPPT algorithm extracts the maximum power from solar PV array at three different conditions.

Case I: at variable irradiance and constant temperature
Case II: at variable temperature and constant irradiance
Case III: at variable temperature and variable irradiance which is a new technique when compared to the other conventional methods.

These individual case results are presented in section 3&7. The proposed system structure with the asynchronous motor drive is presented in Fig. 7

![Diagram](image)

Fig 7. Proposed MPPT system with DC-DC converter and Asynchronous motor drive

The point of operation of the PV array is adjusted by varying the duty cycle. DC-DC converter boosts the PV array voltage and also increases the maximum utilization of PV array by operating at MPP. Boost converter increases the array output voltage up to 400 Volts with the help of SVM based inverter.

The minimum inductor value \(L_{\text{MIN}}\) is calculated from Eq. (28) to ensure the continuous inductor current

\[
L_{\text{MIN}} = \left(\frac{V_{\text{DC}}}{f_0 \times I_{\text{PV}}}ight)
\]

Where \(V_{\text{DC}}\) is DC output voltage, \(D\) is duty ratio, \(f_0\) is switching frequency of the converter, \(I_{\text{PV}}\) is average output current. The minimum capacitance value \(C_{\text{MIN}}\) can be calculated using Eq. (29)

\[
C_{\text{MIN}} = \frac{V_{\text{DC}}}{f_0 \times I_{\text{PV}}}
\]

The switching frequency selection is trade-off between switching losses, cost of switch and the converter efficiency.

VII. RESULTS AND DISCUSSION

The proposed model has been developed with Matlab/Simulink. The input to the module is temperature and solar irradiance. At standard test conditions (STC) containing 60 cells to produce 250 Watt power and such 6 modules are connected in order to form solar PV array. From simulation results we got the array generated open circuit voltage is 75.96 Volts with short circuit current about 26.01 Amps and the maximum power obtained at MPP is 1500 Watts. These results are shown in Fig. 8

![Graph](image)

Fig 8. I-V & P-V characteristics obtained from PV array

| Time in (am/pm) | Temperature in °C | Array Power in Watts |
|----------------|------------------|---------------------|
| 08.00          | 30.75            | 188.70              |
| 09.06          | 33.35            | 642.94              |
| 10.00          | 38.25            | 725.62              |
| 11.00          | 39.55            | 839.61              |
| 12.00          | 40.50            | 853.60              |
| 12.10          | 40.68            | 866.36              |
| 13.00          | 41.35            | 801.78              |
| 14.00          | 40.08            | 662.70              |
| 15.00          | 38.42            | 611.00              |
| 16.00          | 37.32            | 453.12              |
| 16.30          | 37.06            | 381.51              |

a. Simulation Results of Asynchronous Motor Drive with Inverter

Simulation results are obtained with the reference speed of 1400 RPM and switching frequency of 5 KHz. The performance of motor parameters such as stator phase currents, torque and speed are analyzed in Fig. 10-17.

Here the motor drive is being fed with 400 Volts supply with the help of boost converter and inverter. The output voltages of the inverter are shown in Fig. 9

![Graph](image)

Fig 9. Inverter output voltages
b. Simulation Results of Asynchronous Motor Drive at starting

For the asynchronous motor drive the maximum current and the ripple content in the torque is reduced during starting in order to reach the early steady state. With the proposed MPPT the maximum torque, stator phase current and the speed are obtained as 12.28 N-m, 7.596 Amps and 1400 RPM respectively. It is observed that the ripple content in the torque is 0.29 with lot of improvement compared to the other existed methods. Due to this better speed response is obtained. These results are presented in Fig. 10-12.

![Fig 10. Stator phase current responses with conventional and proposed MPPT controller at starting](image)

![Fig 11. Speed responses with conventional and proposed MPPT controller at starting](image)

![Fig 12. Torque responses with conventional and proposed MPPT controller at starting](image)

a. Simulation Results of Asynchronous Motor Drive at steady state condition

The steady state responses of the stator phase currents, torque and speed with conventional and proposed MPPT are observed in Fig. 13-14. Here torque ripple with the proposed MPPT is improved a lot i.e. it is observed that the torque ripple with the conventional and proposed MPPT are 0.35 and 0.05 respectively. The better speed response is obtained with the proposed MPPT controller.

![Fig 13. Stator phase current, torque and speed responses with the conventional MPPT controller at steady state](image)

![Fig 14. Stator phase current, torque and speed responses with the proposed MPPT controller at steady state](image)

a. Simulation Results of Asynchronous Motor Drive at transients with step change in load

The response during the transients with step change in load torque of 8 N-m is applied at 0.7 sec and removed at 0.9 sec is shown in Fig. 15-17. The ripple content in the current and torque is reduced with the proposed MPPT. Also the speed decrement is little less with the proposed MPPT during the load change.

![Fig 15. Stator phase current responses with conventional and proposed MPPT controllers at transients with step change in load](image)

![Fig 16. Torque responses with conventional and proposed MPPT controllers at transients with step change in load](image)
VIII CONCLUSION

The PV array model with the artificial neural network (ANN) based MPPT controller is tested. From this the performance of the asynchronous motor drive is analyzed with comparing the both conventional and proposed ANN MPPT controller results. Also the behavior of the proposed ANN MPPT is observed with practical validations during a partially cloudy day. PV system with DC-DC boost converter and space vector modulation based technique inverter enhances the system performance with improving the power quality even under abnormal weather conditions. The ripple contents in the torque and stator phase currents are improved a lot with the proposed ANN based MPPT controller. Here the early steady state response of the motor drive is reached along with attaining of better speed response. Thus the utilization and efficiency of the system is improved much with the proposed ANN based MPPT controller.

ACKNOWLEDGEMENT

The funding support given by SERB, Department of Science and Technology (DST), Government of India with vide SERB order No: SERB/ET-069/2013 for the solar based project is acknowledged.

REFERENCES

[1] Roberto Faranda and Sonia Leva, Energy Comparison of MPPT techniques for PV systems. WSEAS Transactions on Power Systems 6(3): 446-455 (2008).
[2] Adel Mellit and Soteris A. Kalogirou, Artificial Intelligence Techniques for Photovoltaic Applications. A Review Progress in Energy and Combustion Science, 34: 574-632 (2008).
[3] Al. Saadi and A. Moussi, Neural Network use in the MPPT of photovoltaic pumping system. Rev. Energy. Ren. Pp.39-45 (2003).
[4] Lian Jiang, D.R. Nayanasri, D.L. Maskell and D.M. Vilathgamuwa, A Simple and Efficient Hybrid Maximum Power Point tracking Method for PV Systems Under Partially Shaded Conditions. IEEE Industrial Electronics Society Pp.1513-1518 (2013).
[5] Hong Hee Lee, Le Minh Phuong, Phan Quoc Dzung, Nguyen Truong Dan Vu and Le Dinh Khoa, The New Maximum Power point Tracking Algorithm using ANN-based Solar PV Systems. IEEE TENCON Pp. 2179-2184 (2010).
[6] M. Sheraz and M.A. Abido, An Efficient MPPT Controller using Differential Evolution and Neural Network, IEEE Power and Energy (PECon), Pp.378-383 (2012).
[7] Jinbang Xu, Anwen Shen, Cheng Yang, Wenpei Rao and Xuan Yang, ANN based on Incremental Conductance Algorithm for MPP Tracker. IEEE Bio-Inspired Computing: Theories and Applications (BIC-TA), Pp.129-134 (2011).
[8] Long Jie and Chen Ziran, Research on the MPPT Algorithms for Photovoltaic System Based on PV Neural Network, IEEE Control and Decision Conference, Pp.1851-1854 (2011).
[9] Nian Zhang, P.K. Behera and C. Williams, Solar Radiation Prediction Based on Particle Swarm Optimization and Evolutionary Algorithm using Recurrent Neural Networks, IEEE Systems Conference, Pp.280-286 (2013).
[10] R. Ramaprabha, B.L. Mathur and M. Sharanaya, Solar Array Modeling and Simulation of MPPT using Neural Network, IEEE Transactions on Control, Automation, Communication and Energy and Conservation, Pp.1-5 (2009).
[11] M. Adly, M. Ibrahim and H. El Sherif. Comparative study of improved energy generation maximization techniques for photovoltaic systems, IEEE Power and Energy Engineering Conference (APPEEC), Pp.1-5 (2012).
[12] Qiang Mei, Mingwei Shan, Lijing Liu and M. Josep Guerrero, A novel improved variable step-size incremental tal-resistance MPPT method for PV systems,” IEEE Transactions on Industrial Electronics 58(6): 2427-2434 (2011).
[13] J. J. Joshi, P. Kartthick and R. S. Kumar, A solar panel connected multilevel inverter with SVM using fuzzy logic controller. IEEE International Conference on Energy Efficient Technologies for Sustainability (ICEETS), Pp.1201-1206 (2013).
[14] M. Aleenejad, H. Iman-Eini and S. Farhangi, A minimum loss switching method using space vector modulation for cascaded H-bridge multilevel inverter, IEEE 20th International Conference on Electrical Engineering (ICEEE), Pp.546-551 (2012).
[15] C. Sreeja and S. Arun, A novel control algorithm for three phase multilevel inverter using SVM, IEEE PES Innovative Smart Grid Technologies-India (ISGT India), Pp. 262-267 (2011).
[16] A. Mbarushimana and Xin Ai, Real time digital simulation of PWM converter control for grid integration of renewable energy with enhanced power quality, IEEE Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), Pp.712-718 (2011).
[17] Dong Hwa Kim, GA-PSO based vector control of indirect three phase induction motor. Elsevier Science Direct Applied Soft Computing 7(2): 601-611 (2007).
[18] Durga Sukumar, Jayachandranath Jitendranath, Suman Sarani, Three-level Inverter-fed Induction Motor Drive Performance Improvement with Neuro-fuzzy Space Vector Modulation. Electrical Power Components and Systems 42(15): 1633-1646 (2014).