Induction Motor Drive Using LLC Resonant Converter Supplied with Solar PV

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Abstract- Resonant Converter is a highly efficient converter with high switching frequency range. To cater the power requirement, Solar Photovoltaic (PV) is used as an input source to this Resonant converter. To achieve maximum efficiency of Solar PV system, Maximum Power Point Tracking (MPPT) technique is used. There are Direct and Indirect methods used to achieve MPPT. In this paper, Perturb and Observe (P&O) method is used to simulate results of the Resonant Converter. The modeling of system using this method with their respective outputs are presented in this paper.

Keywords – LLC Resonant Converter, Induction Motor Drive, MPPT, Perturb and Observe, Incremental Conductance

I. INTRODUCTION

Solar Energy is widely used to cater with the ever-increasing electrical energy demand. Solar PV arrays have comparatively lesser output efficiency (about 30 – 35%). Hence it is always a great idea to apply certain techniques to make Solar PV operates at its maximum power output point. For this, MPPT systems are used. MPPT makes it possible to operate Solar PV near to its maximum operating point region. There are multiple ways of achieving MPPT. These are Direct and Indirect methods. Figure below shows various methods of achieving this MPPT.

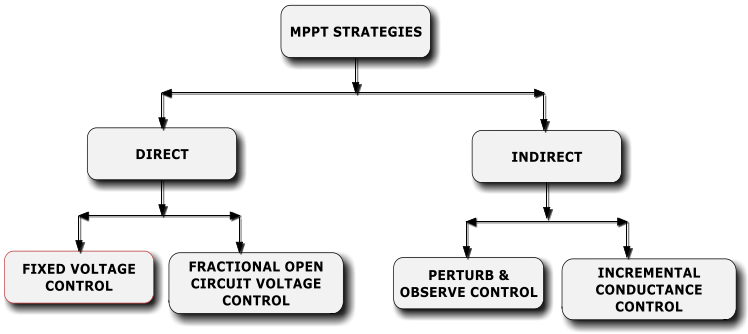

Figure 1. Various MPPT Methods

In Indirect MPPT, simple assumptions and periodic estimations of MPPT are made with easy measurements just to fix the operating voltage of Solar PV module on seasonal variations. This is not a very accurate method.
Direct methods evolve direct measurements of Voltage, Current or Power and provides more faster accurate response. These are also called Hill Climbing algorithms.
In P&O method, Perturbation is provided to PV module or array voltage [1]. This will translate increase or decrease in power. The flowchart of this P&O algorithm is shown below in figure 2.

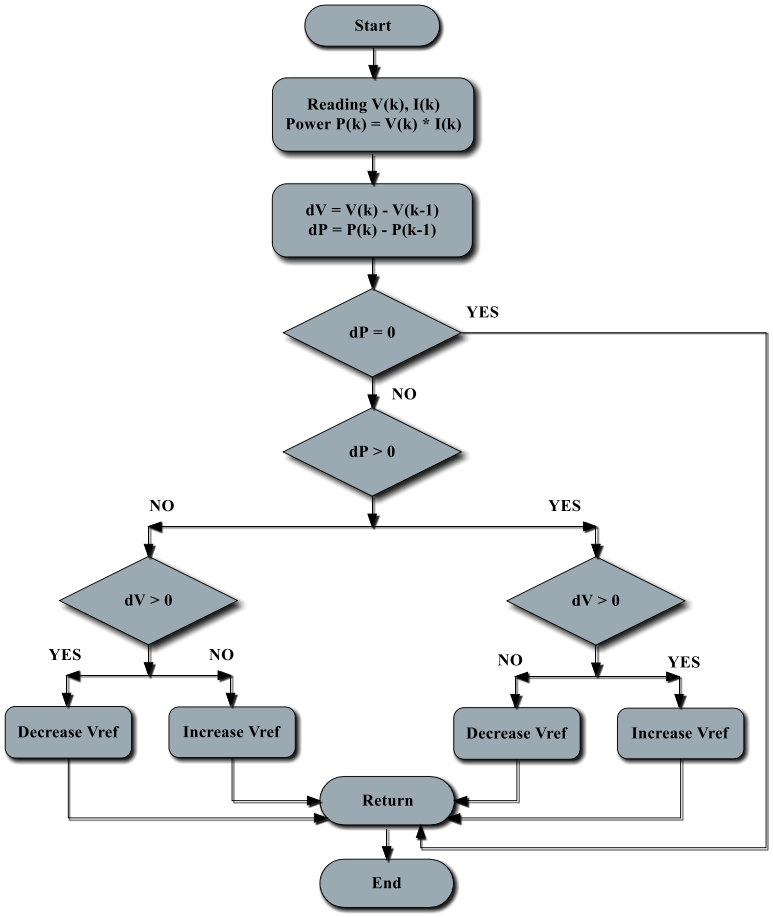

Figure 2. P & O Algorithm Flowchart

In case of Incremental Conductance method, algorithm imposes voltage on PV module at every iteration and measures the incremental change in conductance and compares it with instantaneous conductance and decides if the operating point is to the left or right of maximum power point [2]. The flowchart of this P&O algorithm is shown below in figure 3.

Resonant converters are mostly used converters now a days because of their output impedance can be regulated from zero to infinite. This is achieved using frequency modulation control. They can operate at very high efficiency since the switching losses are very less (turn ON and OFF of the switch occurs near the natural current zero instant). Circulating energy is very less in these LLC resonant converters compared to Series Resonant Converters (SRC), Parallel Resonant Converters (PRC) and Series Parallel Resonant Converters (SPRC). Hence LLC type Resonant Converter is proposed here for Solar Array system to achieve high efficiency. High frequency transformer is used here for boosting output of LLC Resonant converter and also to provide isolation for Safety requirements.

In this paper, LLC Resonant Converter model and its design is proposed to be used along with Solar PV Array. Simulation study of design and associated results are verified using MATLAB SIMULINK.

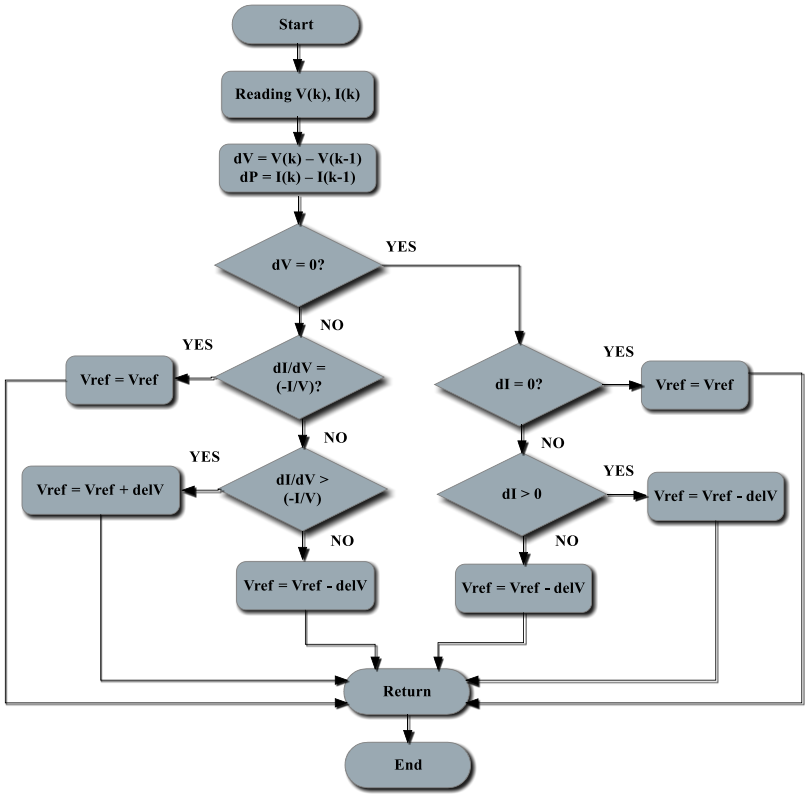

Figure 3. Incremental Conductance Algorithm Flowchart

II. DESIGN OF AN LLC RESONANT CONVERTER

Figure 4 shows the block diagram of a proposed LLC Resonant Converter for Induction Motor Drive application. Here MOSFET's are used as switches and are operating at high frequency range (100 kHz).

Figure 5 shows the proposed LLC Resonant Converter circuit. The Resonating Tank design consists of Resonating Capacitor Cr, the Leakage Inductance Lr, and Magnetizing Inductance Lm of the Transformer [3] [4] [5]. The voltage output is regulated by controlling the switching frequency fs. Switches Q1, Q2, Q3 and Q4 are MOSFET's. D1 – D4 forms the Diode Bridge FW Rectifier [7] [8]. The transformer used here is having ratio of n = 1:10. It not only step up the voltage level but also provides necessary isolation to the output and input circuit [11]. The inductance of transformer is a part of this LLC RC network [17].

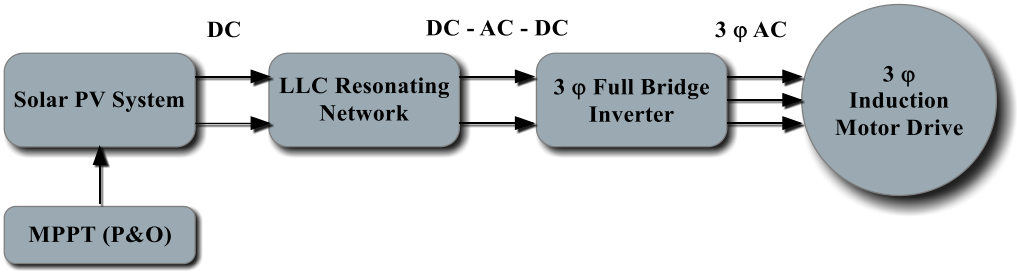

Figure 4. Block Diagram of a Proposed LLC Resonant converter System

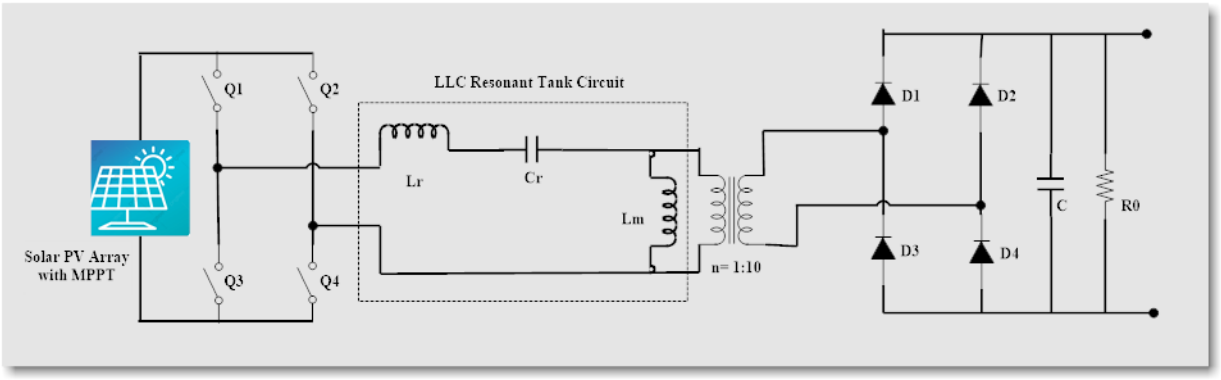

Figure 5. Proposed LLC Resonant Converter Model

The MPPT Algorithm proposed here takes care of maintaining output voltage corresponding to Maximum Power Point of the Solar PV. Perturb and Observe (P&O) algorithm is used to achieve Maximum Power Point [13-14]. The Solar PV Array used as a source is having following parameters as shown in table 1 below. The Maximum Power Point is achieved using Perturb and Observe Algorithm. Duty ratio control is achieved using the same so that Solar PV array should give stable output voltage corresponding to Maximum Power operating point.

Table-1 Parameters of Solar PV Array used

Parameter	Abbreviations	Value
Maximum Power Output	Pmax	180 Watts
Open circuit voltage	Voc	63.3 Volts
Short Circuit Current	Isc	7.6 Amp
Irradiance	Q	1000 W/m^2
Temperature	T	25 ^{0}C

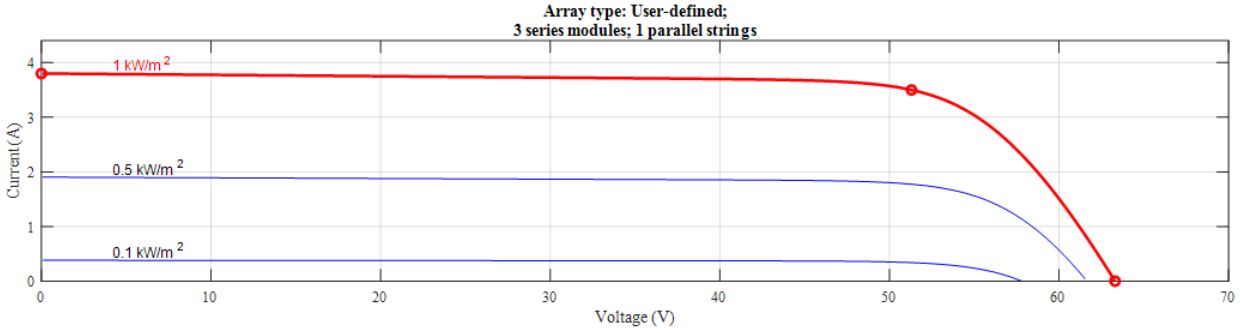

Figure 6. I – V Characteristics of Solar PV Module

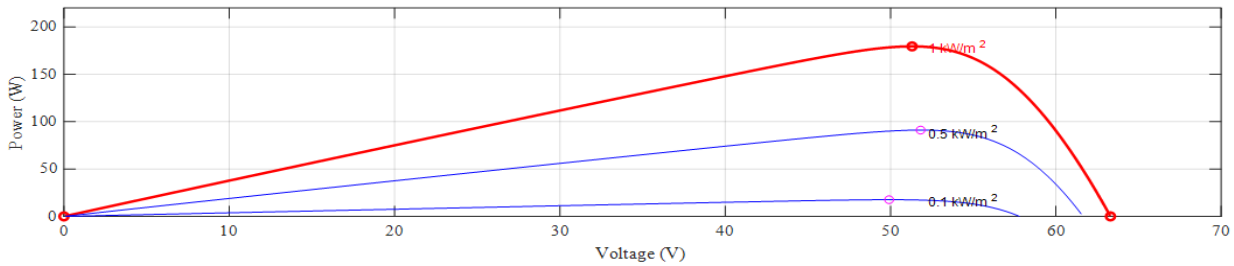

Figure 7. P – V Characteristics of Solar PV Module

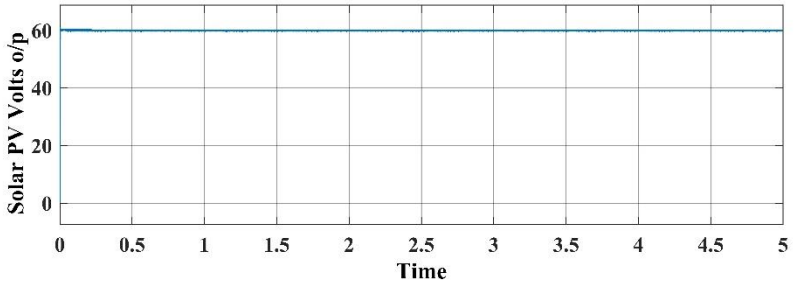

Figure 8. Voltage O/P of Solar PV Module

After that we select the ordered coefficient from 1 to N to get N coefficient. the formulae of watermark embedding are as follows.

2.1. LLC Resonant Converter Design Considerations –

The design of a proposed LLC Resonant Tank circuit [12] [15] [16] is based on calculations as given in equations (1) to (8).

Table-2 Design Parameters of an LLC Resonant Converter

Parameter	Abbreviations	Value
Input Voltage	**(V_{DC})**	**60 Volts**
Output Voltage	**(Vo)**	**415 Volts**
Output Power	**(Po)**	**2.32 kW**
Switching Frequency	**(fs)**	**100 kHz**
Resonating Frequency	**(fr)**	**5 kHz**
Resonating Capacitor	**(Cr)**	**4.1733e-6 F**
Leakage Inductance	**(Lr)**	**0.10116e-6 H**
Magnetizing Inductance	**(Lm)**	**0.5058e-6 H**
Transformer Ratio	**(n)**	**1:10**

$$\mathrm{Cr} = \frac{1}{2*\pi*\mathrm{Q}*\mathrm{fo}*\mathrm{Rac}} \quad (1)$$

$$\mathrm{Lr} = \frac{1}{(2*\pi*\mathrm{fo})^2*\mathrm{Cr}} \quad (2)$$

$$Rac = \frac{8*n^2*R_L}{\pi^2} \quad (3)$$

$$Magnetizing\ Inductance, L_m = \frac{R_L}{2\pi\ f_r} \quad (4)$$

$$n = \frac{Np}{Ns} = \frac{Vin_{max}}{2*(Vo+Vf)} * Mmin \quad (5)$$

$$Mmin = \sqrt{\frac{m}{m-1}} \quad (6)$$

$$Resonant\ Frequency, f_r = \frac{1}{2\pi\ \sqrt{L_r\ C_r}} \quad (7)$$

$$m = Inductance\ Ratio = \frac{L_m}{L_r} \quad (8)$$

Selecting m=5 and quality factor corresponding to m chosen as 0.4, the calculated parameters of LLC Resonant Converter are as given in table 2 [6] [9 - 11].

The Induction motor load is considered to check the proposed system. The parameters of Induction Motor drive load are given below in table 3.

Table-3 Parameters of Induction Motor Drive

Parameter	Abbreviations	Value
Input Voltage $_{L\text{-}L}$, rms	**(V_{in})**	**415Volts**
Output Power	**(Po)**	**2.3 kW**
Frequency	**(f)**	**50 Hz**

III. SIMULATION RESULT

The proposed design and model is simulated using MATLAB / Simulink. The simulation results for respective LLC Resonant converter voltage output, Induction Motor Outputs for Speed, Torque, Stator Voltage $_{L\text{-}L}$, Stator Current are shown below in figure (9) to figure (13).

The respective resulted values of different Induction Motor Parameters are listed below in table 4.The proposed scheme is tested using ordinarily image processing. From the simulation of the experiment results, we can draw to the conclusion that this method is robust to many kinds of watermark images.

Table-4 Induction Motor Simulation Output Results

Parameter	Abbreviations	Value
Stator Voltage, rms	**($V_{L\text{-}L}$)**	**415 volts**
Stator Current, rms	**(I_{FL})**	**4.57 amps**
Full Load Speed	**(N_{FL})**	**1431 rpm**
Electromagnetic Torque	**(Te)**	**14.42 N*m**

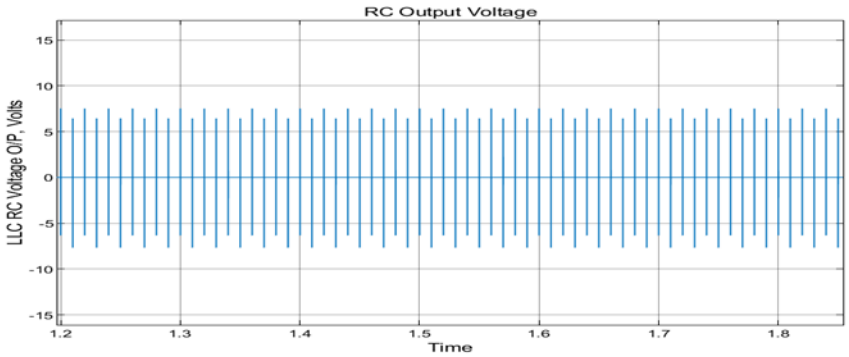

Figure 9. LLC Resonant converter O/P voltage waveform

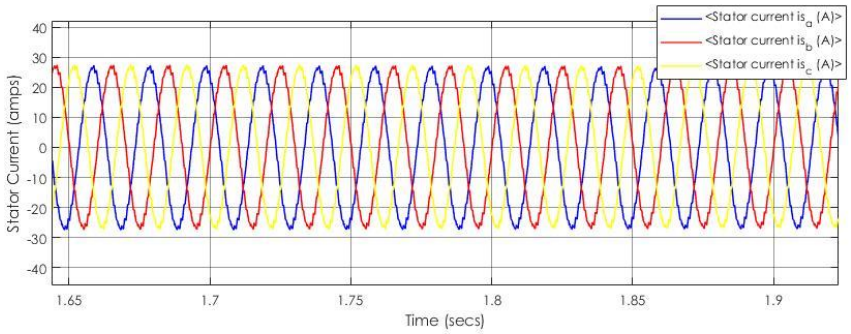

Figure 10. Induction Motor stator current waveform

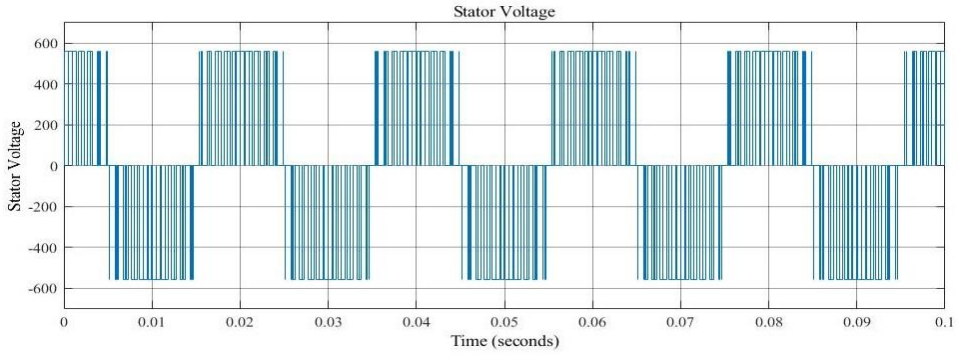

Figure 11. Induction Motor Stator Voltage Waveform

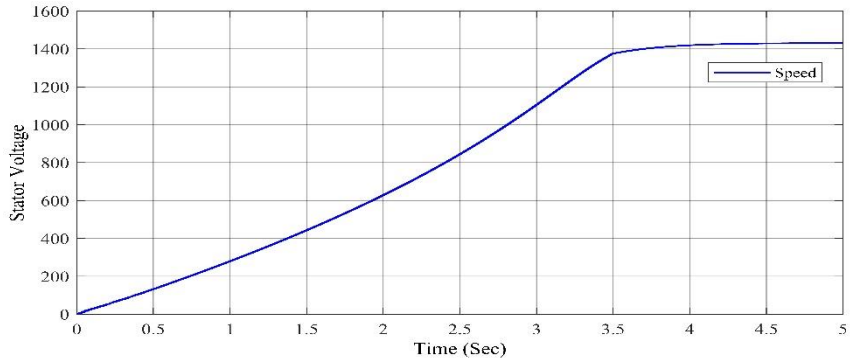

Figure 12. Speed Curve of Induction Motor Drive

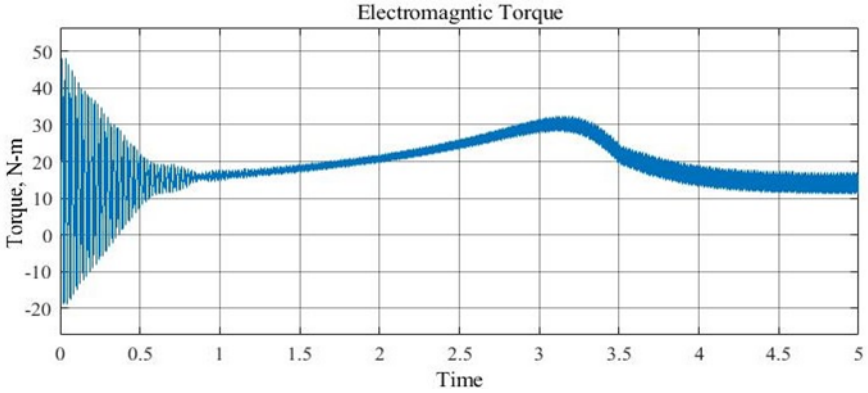

Figure 13. Electromagnetic Torque curve for Induction Motor Drive

IV.CONCLUSION

The Perturb and Observe algorithm based MPPT system is working fine. The duty ratio control is obtained to stabilize Solar PV output voltage corresponding to Maximum Power Point. The LLC tank network is providing necessary voltage to run Induction Motor Drive. The output parameters of Induction Motor showing satisfactory simulation result. All simulation results are obtained using MATLAB/SIMULINK.

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