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Maximum Power Point Tracking For Solar Energy System Using Linear Quadratic Regulator

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***Abstract*—This paper proposes how energy can be utilized to the maximum extent from the solar photo-voltaic by using the maximum power point tracking system. The maximum power point tracking is used to get the maximum output during varying irradiance levels for photovoltaic system. The linear quadratic regulator is used to get the optimized output from the photovoltaic system. The cost function for the system based on the system matrices is used in the linear quadratic regulator which is used with maximum power point tracking algorithm. The maximum power point tracking is achieved using various algorithms such as perturb and observe, incremental conductance, current sweep, constant voltage. Various MPPT methods have different advantages and disadvantages depending on the constraints. When there is variations in the irradiance level the hill climbing algorithm have much efficiency. The sensors such as temperature sensor, current and voltage sensors are used to give the input to the MPPT algorithms to get the maximum possible output from the system.**

Keywords*—*Maximum Power Point Tracking(MPPT); Linear Quadratic Reguator (LQR);Photo-Voltaic (PV); perturb and observe algorithm; Incremental Conductance algorithm

I. INTRODUCTION

Energy is the basic need that is essential for economic growth and development of a country. Energy is being consumed in any form, either as electrical energy, mechanical energy, thermal energy, or in any useful forms. Before the industrial revolution people were dependent only on man power and animal power. Life was must simple and unsophisticated, hence the environment was relatively undisturbed and pure. The introduction of electrical machines due to the industrial revolution along with the commercial availability of electricity made the birth of new electrical age. Energy has been the life and blood for continuous progress of the human life in civilization of world. Thus, with developments in the human life and advancements in the comfort of human life, the energy consumption has also been increased rapidly causing drastic change.

The demand for electricity cannot be met due to the insufficient production of electricity around the country and as most of our power stations depend primarily on fossil fuel, because of the shortage of fuel supply some power plants are unable to produce power of their rated generation capacity. The fossil fuels get depleted rapidly due to rapid consumption and hence scarcity of fuel will occur in few years. The insufficient fuel for electricity generation has decreased the power generation capacity in the whole country. We have failed to use our national resources in every possible way to get maximum power output. Hence result of the power crisis is degradation of the fossil fuel resource, deforestation, environmental pollution is going on which is causing natural disasters. If this continues, industries will face loss due to power crisis; production will become low and eventually economy of the country will fall behind which will cause the major industries to shut down resulting into poverty and unemployment. We must get rid of this by alternative forms known as renewable energy. Renewable energy can help us improve the condition of power crisis and help us move forward economically and environmentally. Moreover, the environmental drawbacks of renewable energy sources are minimum.

II. ENERGY SOURCES

A. *Energy Sources*

Natural resources such as oil, coal, or the sun, which can be used to provide power for light, heat, machines, etc. We are committed to the development of clean and renewable energy sources.

The world's energy resources can be divided into fossil fuel, nuclear fuel and renewable resources. Based on long-term availability the energy resources are classified as,

- Non-renewable energy resources.
- Renewable energy resources.

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B. Non Renewable Energy

A non-renewable energy source is a source that does not restore itself at significant rate for sustainable economic extraction in meaningful human time-frames. An example is carbon-based, organic fuel. The organic material when subjected to changes with the aid of heat and pressure becomes a fuel such as oil or gas.

Disadvantages of Non-renewable Energy Resources

- Fossil fuels generate pollution. These pollutants degrade the environment, cause health hazards. Mainly carbon dioxide which causes global warming.
- Coal a petrochemical is used as raw material for chemical, pharmaceutical and paint industries. In long-term it is desirable to conserve coal for future needs.
- The waste materials in nuclear plants has radioactivity quotients of dangerous levels, it remains above the safe limit for long period and is health hazard.
- Possibility of accidental leakage of radioactive material from reactor is another safety issue.
- Non-renewable sources will finish up one day.
- Conventional sources are not sufficient to meet the growing demand.

Due to these reasons it has become necessary to identify non-conventional or renewable resources to reduce too much dependence on conventional or non-renewable resources. India is the only country having a full-fledged ministry devoted especially to developing new and renewable energy sources.

C. Maintaining the Integrity of the Specifications

A renewable energy source is natural source that can replenish in due time compared to the usage, either through biological reproduction or other naturally recurring processes. Renewable resources are a part of Earth's natural environment and the largest components of its ecosphere.

Advantages of Renewable energy

- Its acts as a solution to the energy problem for the stabilization of carbon dioxide emissions and other greenhouse gases. Replaces energy generation plants which use conventional sources lead to a reduction in the emission of pollutants such as sulphur and nitrogen oxides which cause acid rain.
- Domestic sources of energy and contribute to increasing energy independence and society of energy supply at the national level.
- Geographically dispersed leading to the decentralization of the energy system making it possible for energy needs to be met at a local and regional level reducing losses from energy transmission.
- They provide opportunities for rational use of energy sources because they cover wide range of energy needs.
- Low operating costs which are not influenced by fluctuations in the international economy and especially in prices for conventional fuels.

16% of global energy consumption presently comes from renewable resources, 10% of energy from traditional biomass used for heating, and 3.4% from hydroelectricity. New renewable account for another 3% and are increasing rapidly. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond.

Renewable energy sources all over wide geographical areas in contrast to other energy sources which are concentrated in a limited number of countries to particular areas. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits. In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power. While many renewable energy projects are large-scale, renewable technologies are also suited to rural and remote areas and developing countries.

III. Maximum Power Point Tracking

Maximum Power Point tracking is a technique that is used to get maximum possible power from one or more photo-voltaic (PV) devices. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces non-linear output efficiency which can be analyzed based on I-V curve. It is MPPT system to sample the output of the cells and apply the proper resistance load to obtain maximum power for any

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given environmental conditions. MPP (Maximum power point) is the product of the MPP voltage (V_{mpp}) and MPP current (I_{mpp}). MPPT devices are typically used in electric power system that provides voltage or current conversion, filtering, and regulation for various loads such as power grids, batteries, or motors.

A. *Perturb and Observe Algorithm*

In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is perturb and observe method which is most common, this method results in oscillations of power output. It is referred as hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. Perturb and observe is the most commonly used MPPT method due to its ease of implementation. Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

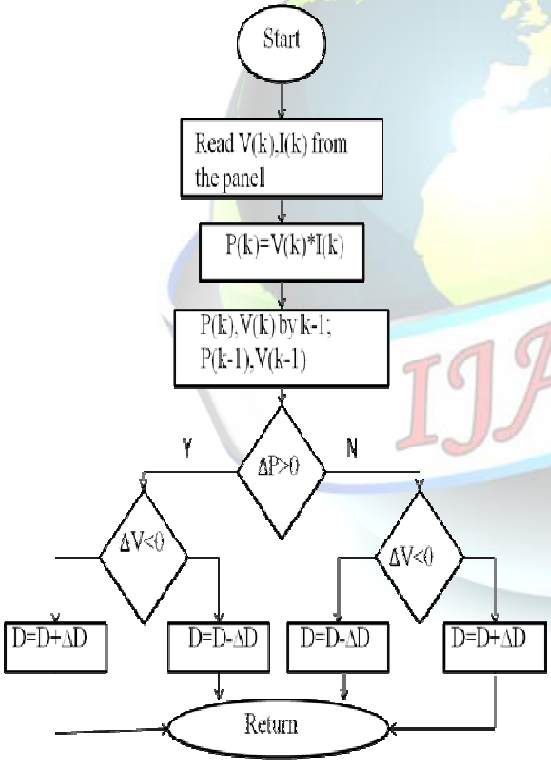

Fig 1 Flowchart of perturb and observe algorithm

B. *Incremental Conductance Algorithm*

Incremental Conductance (INC) method is a type of MPPT algorithm. This method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV). INC method provides rapid MPP tracking even in rapidly changing irradiation conditions with higher accuracy than the perturb and observe method.

The power-voltage curve's slope is null at the MPP, negative to the right of the MPP and positive to the left of the MPP. INC computes the maximum power point by comparison of the incremental conductance (ΔI/ΔV) to the instantaneous conductance (I/V). When the incremental conductance is zero, the output voltage is ascertained to be the MPP voltage and fixed at this voltage until the MPP encounters a change due to the change in irradiation conditions. Then the process above is repeated until a new maximum power point is reached.

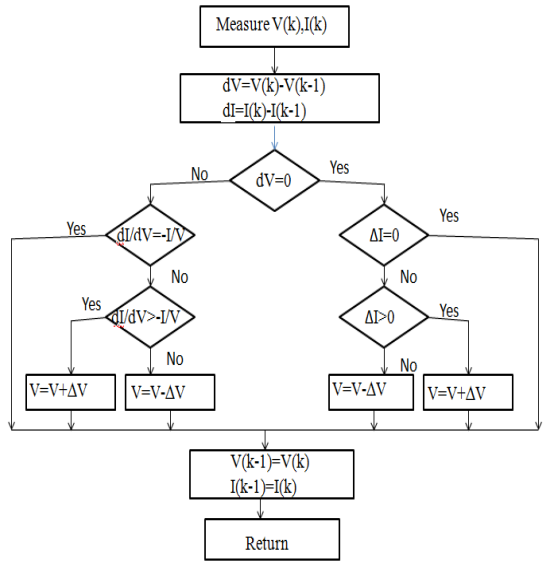

Fig 2 Flowchart of incremental conductance algorithm

IV. Linear Quadratic Regulator

The term "linear quadratic" refers to the linear system dynamics and the quadratic cost function. LQR design is based on the selection of feedback gain such that the cost function J is minimized. This ensures that the gain selection is optimal for the cost function specified. For LQR design the system need to be described by state space model:

$$\dot{x} = Ax + Bu \quad \text{--------(1)}$$

$$y = Cx + Du \quad \text{--------(2)}$$

The performance index is defined as,

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$$J = \int_0^\infty (x^T Qx + u^T Ru)dt \text{ --------(3)}$$

where, Q and R are the weight matrices. Q is positive definite or positive semi-definite real symmetric matrix and R is positive definite symmetric matrix. The feedback control function limits to a linear function so that,

$$u = - Kx \text{ --------(4)}$$

where K is given by,

$$K = R^{-1}B^T P \text{ --------(5)}$$

and P can be determined by solving the continuous time algebraic *Riccati* equation

$$A^T P + PA - PBR^{-1}B^T P + Q = 0 \text{ --------(6)}$$

V. SIMUALTION RESULTS

The simulation for the test system is done by MATLAB / Simulink. The test system is shown in fig. 3 and the P&O controller is shown in fig 4. The value of delta is obtained in the plot which is shown in fig 4 and output voltage and current in fig 5. The simulation is done for a test system with a solar panel as source and the output of solar is given to a boost converter which is supplying the load.

The LQR design is done using the model of boost converter and the LQR is used as controller with MPPT algorithm. The system output for the LQR based P&O MPPT algorithm controller is shown is fig 7. The output gets stabilized faster than the MPPT algorithm. The system is stable and the output settling time is less when compared to the conventional P&O Algorithm.

The simulation is carried out for the test system using solar cell to form solar panel which has the following ratings as mentioned in table 1.

The incremental conductance algorithm controller is shown in fig 8. The LQR design is done using the model of boost converter and the LQR is used as controller with MPPT algorithm. The controller simulation of incremental conductance algorithm is shown in fig 9. The system output for the LQR based incremental conductance MPPT algorithm controller is shown is fig 10.

TABLE I. SIMULATION DATA

	Parameter	*Value*
Solar Cell	Short Circuit Current, ISC	7.34 A
	Open Circuit Voltage, VOC	0.6 V
	Irradiance, Ir	1000 W/m2
Solar Array	10 x Solar Cells	10 x 6 = 6 V
Solar Panel	5 x Solar Aray	5 x 6 = 30 V

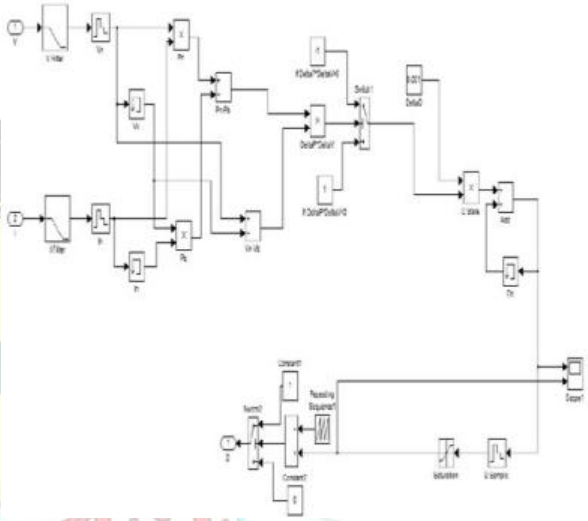

Fig 3 Simulation Diagram P&O Algorithm Controller

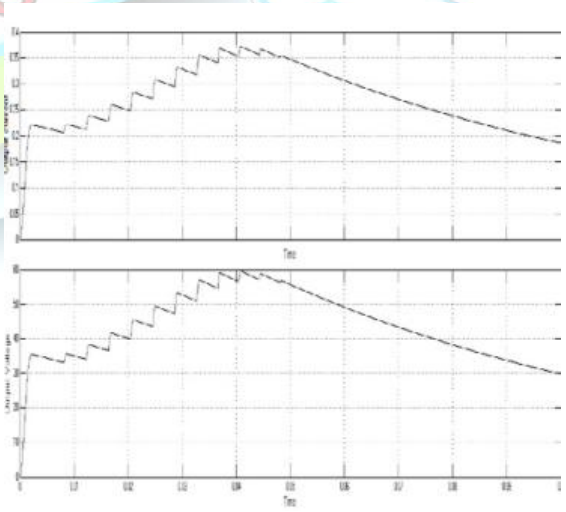

Fig 4 Output Waveforms for P&O Algorithm

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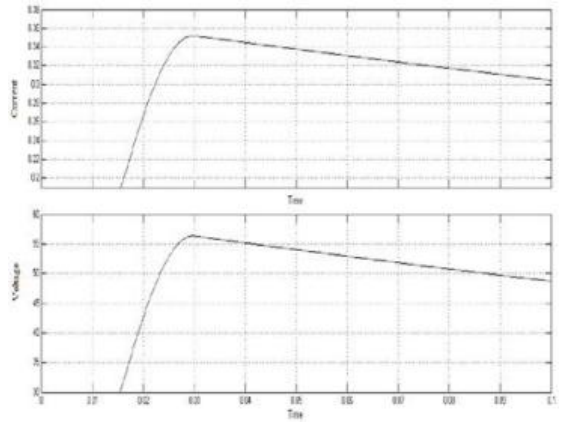

Fig 5 Output Waveforms for P&O Algorithm using LQR

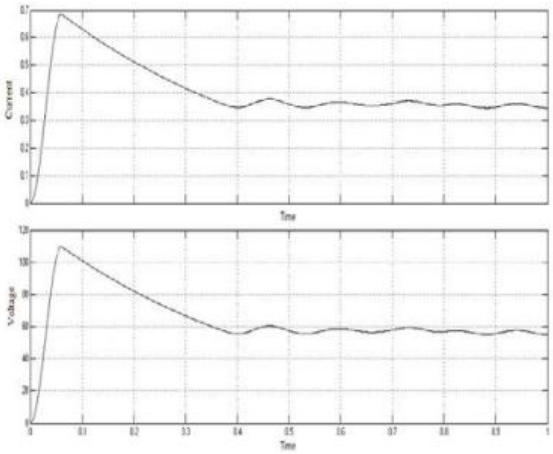

Fig 8 Output Waveforms for Incremental Conductance Algorithm

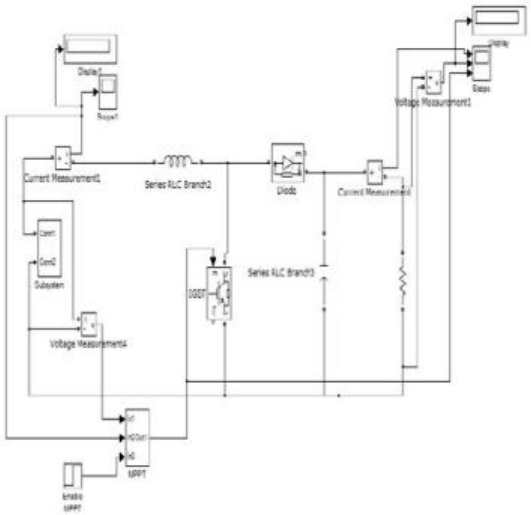

Fig 6 Simulation diagram for Incremental Conductance Algorithm

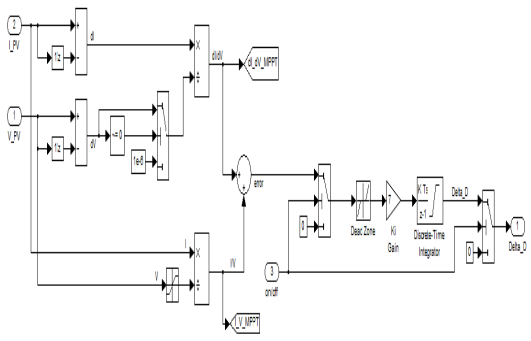

Fig 7 Incremental Conductance Algorithm Controller

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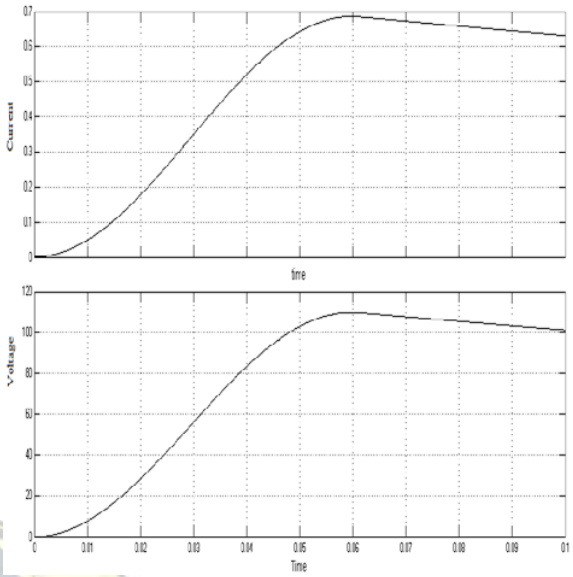

Fig 9 Output Waveforms for Incremental Conductance Algorithm with LQR

VI. CONCLUSION

The linear quadratic regulator based maximum power point tracking for the solar energy system is proposed. The proposed controller has the advantage that cost function has been taken into consideration depending on various parameters such as current, temperature, irradiance which gives the maximum power point. The linear quadratic controller has been proposed for perturb and observe algorithm and incremental conductance algorithm for maximum power point tracking.

The simulation is carried out for test system using MATLAB/ Simulink. The Linear quadratic regulator has the advantage of the system with robust and stable. The system has less settling time and reduced steady state error.

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