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Modelling and Simulation of Hybrid Solar Cell and Fuel Cell for Suburban Electrification

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ABSTRACT: Solar photovoltaic technology is considered as one of the pure and clean technologies to produce electricity, but seems unattractive towards the use of it as a complement of electricity due to its low efficiency and high initial cost. As a result of its low efficiency it is nearly impossible to exploit the maximum solar power coming out of array therefore at its highest energy conversion output it leads to the operational failure of the device. As the radiation and temperature has their effects on the maximum power point, it is likely impossible to provide power operation at optimum level during all radiation levels. From years of research and numerous MPPT techniques are introduced, refined, enforced and implemented with a proper execution. Different research groups have advocated different research methods which consist of little literature, where correlation between varieties of MPPT techniques is executed in terms of reliability, time of response and efficiency of conversion. This inspection gives a brief comparison among the realization of different MPPT methods and results a new MPPT technique with improved capability than the existing ones. The analysis done in this paper is as follows: At first, a solar PV array model based on MATLAB is first modelled and examined for validation following the employment of different techniques of MPPT under varying temperature on this PV array and different conditions for the effectiveness study of the particular MPPT technique.

KEYWORDS: Solar PV array, SOFC, MPPT, Stability, Solar PV System.

I. INTRODUCTION

The SOFC system has relatively simple and response to load changes makes them suitable for large stationary power generations. Hydrogen ions migrate to the cathode through the electrolyte and electrons produced at the anode flow through an external circuit to the cathode. At the cathode, they are combining with oxygen to form water. The flow of electrons through the external circuit provides the current cell. In order to storage energy, Hydrogen and Oxygen are obtained from water by passing a direct current in a process known as electrolysis. A fuel cell consists of an electrolyte sandwiched between two electrodes. The electrolyte has a special property that allows positive ions (proton) to pass through while blocking electrons. Hydrogen gas passes over one electrode, called an anode, and with the help of a catalyst, separates into electrons. The protons flow to the other electrode, called an anode, and with the help of a catalyst, separates into electrons. The protons flow to the other electrode, called a cathode, through the electrolyte while the electrons flow through an external circuit, thus creating electricity the hydrogen protons and electrons combine. Solar energy has become a very potential new energy. Grid-connected photoelectric (PV) system does not require bulk and loss battery and reduces transmission losses.[1] As conventional sources of energy are rapidly depleting and the cost of energy is rising, photovoltaic energy becomes a promising alternative source. The PV array produces the dc power, and hence power electronics and control equipment point are required to convert dc to ac power. A voltage source inverter (VSI) is used to convert dc power produced by PV array into ac power and this ac power is injected into the utility gird. The control system consists of current strategy and voltage control strategy. Current control strategy is used to achieve the dc voltage regulation at dc link and unity power factor at gird and the voltage control strategy is applied to achieve maximum power point tracking. Maximum power point tracking (MPPT) can effectively improve

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the solar energy conversion of PV systems.[4] Almost all the small, point of use photovoltaic power system that are in use today incorporate an energy storage element to provide during periods of inclement weather and at night. Storage via secondary batteries provides a simple system having minimal environmental impact and needing little maintenance. The main technical factors over the past decade that have led to improved PV system performance.

II. FUEL CELL TECHNOLOGY

The SOFC is considered in this paper for distributed generation performance analysis under normal operating conditions. The features of SOFC in can tolerate relatively impure fuel such as obtained from gasification of coal; operate at extremely high temperatures of 500 to 1000^{0}C. The reformer system of SOFC is less complex due to its using carbon monoxide as fuel along with hydrogen. The operating temperature of the reformer and the stacks are compatible. A solid oxide fuel cell is made up of four layers, three of which are ceramics (hence the name). A single cells consisting of these four layers stacked together is typically only a few millimeters thick. Hundreds of these cells are connected in series to form what most people refer to as an “SOFC stack”. The ceramics used in SOFCs do not become electrically and ironically active until they reach very high temperature and as a consequence, the stacks have to run at temperatures ranging from 500 to 1000^{o}C. Reduction of oxygen into oxygen ions occurs at the cathode. These ions can then diffuse through the solid oxide electrolyte to the anode where they can electrochemically oxidize the fuel. In this reaction, a water by-product is given off as well as two electrons. These electrons then flow through an external circuit where they can do work. The cycle then repeats as those electrons enter the cathode material again. Solid oxide fuel cell use dense yttrium – stabilized zirconium (YSZ) which is a solid ceramic material as its electrolyte. These cells operate at 800 to 1000^{o}C where ionic conduction by oxygen ions takes place. The SOFC is a high-temperature operating fuel cells which has high potential in stationary applications. The efficiency of SOFC is in the range of 45-50%, it reaches a high efficiency of 70-75%. It is a solid-state device that uses an oxide ion-conducting non-porous ceramic material as an electrolyte. [2] [3] [5]

The SOFC system has relatively simple and response to load changes makes them suitable for large stationary power generations. Hydrogen ions migrate to the cathode through the electrolyte and electrons produced at the anode flow through an external circuit to the cathode. At the cathode, they are combining with oxygen to form water. The flow of electrons through the external circuit provides the current cell. In order to storage energy, Hydrogen and Oxygen are obtained from water by passing a direct current in a process known as electrolysis. The chemical reactions that take place inside the SOFC and directly involved in the production of electricity as follows. [6] [7] [11]

Anode: $H2\ (g) \rightarrow 2H+\ (as) + 2e^-$
Cathode: $\frac{1}{2} O_2\ (g) + 2H+\ (as) + 2e^-$
Overall: $H_2\ (g) + \frac{1}{2} O_2\ (g) \rightarrow H_2O\ (1)$ + electric energy + waste heat

III. SOLAR CELL TECHNOLOGY (MPPT)

The photovoltaic array is taken here to refer to the structure of panels (modules or sub arrays) that house and support the solar cells in a photovoltaic power system. For system designed for use under concentrated sunlight conditions the definitions includes the focusing and cooling apparatus also. Several photovoltaic cells are connected in series and parallel. Series connection is done to increase the voltage rating and parallel connection is done to increase the current rating of cell. However, the renewable and non-polluting nature of the photovoltaic energy source makes its incorporation into large electrical system highly desirable. Solar panels are normally propped up at an angel and receive more energy per unit area. Photovoltaic’s are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons by the photovoltaic effect. Solar cells produce direct current electricity from sunlight which can be used to power equipment or to recharge a battery. The first practical application of photovoltaic’s was to power orbiting satellites and other spacecraft, but today the majority of photovoltaic modules are used for gird connected power generation. In this case an inverter is required to convert the

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DC to AC. There is a smaller market for off-grid power for remote dwellings, boats, recreational vehicles, electric cars, roadside emergency telephones, remote sensing, and cathode protection of pipelines. [9] [10]

MPPT can effectively improve the solar energy conversion efficiency of PV systems. Where D=Duty cycle &= Perturbation in this paper Perturb and observe (P&O) method is used to achieve this function. If the power increased, the original disturbance would be used, if the power decreased, the original disturbance should be changed. The control is shown in fig MPPT track Ud_{ref} corresponding to maximum power. The non uniformity of the local insulation is usually accounted for by simply sizing the power unit on the basis of likely worst-case conditions. [4]

$$Io = Irs\left[\frac{T}{Tr}\right] 3\exp\left[q\frac{Ego}{Ak}\left\{\left(\frac{1}{Tr}\right)-\left(\frac{1}{T}\right)\right\}\right] \quad (1)$$

IV. MODELING OF SOFC AND PV

For the development of a model the following main assumptions are employed to simplify the hybrid cycle calculations
(1) Steady state operation is considered,
(2) Gases do not leak outside the system.
(3) Adiabatic cell heat loss is negligibly small,
(4) Relative pressure loss remains constant therefore the momentum equation is reduced to the pressure drop,
(5) Temperature of the anode outlet equal to the cathode stream temperature,
(6) Internal distribution of temperature, gas composition and pressure in each component is not taken into account, O2 ion transportation is responsible for electrical current flow,
(7) In the combustion chamber residual chemical species from the anode and injected methane are burned completely,

A solid oxide fuel cell (SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic electrolyte. Advantages of this class of fuel cells include high efficiency, long-term stability, fuel flexibility, low emissions, and relatively low cost. The largest disadvantage is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues. [8]

$$Vcell = No\left[Eo + \frac{RT}{2F}\left(\ln\frac{PH2\sqrt{PO2}}{PH2O}\right)\right] - Ri \quad (2)$$

Where:

Vfc: output voltage of the fuel cell (V) , $Vact$: voltage drop due to activation losses (V)
$Vconc$: voltage drop due to concentration losses (V) , $Vohm$: voltage drop due to ohmic losses (V)
$E0$: standard reversible cell potential (V) ,N: number of cells in stack
R: Universal gas constant, 8.314J/ (mol K) , T: Stack temperature (K) , F: Faraday’s constant, 96487 C/mol

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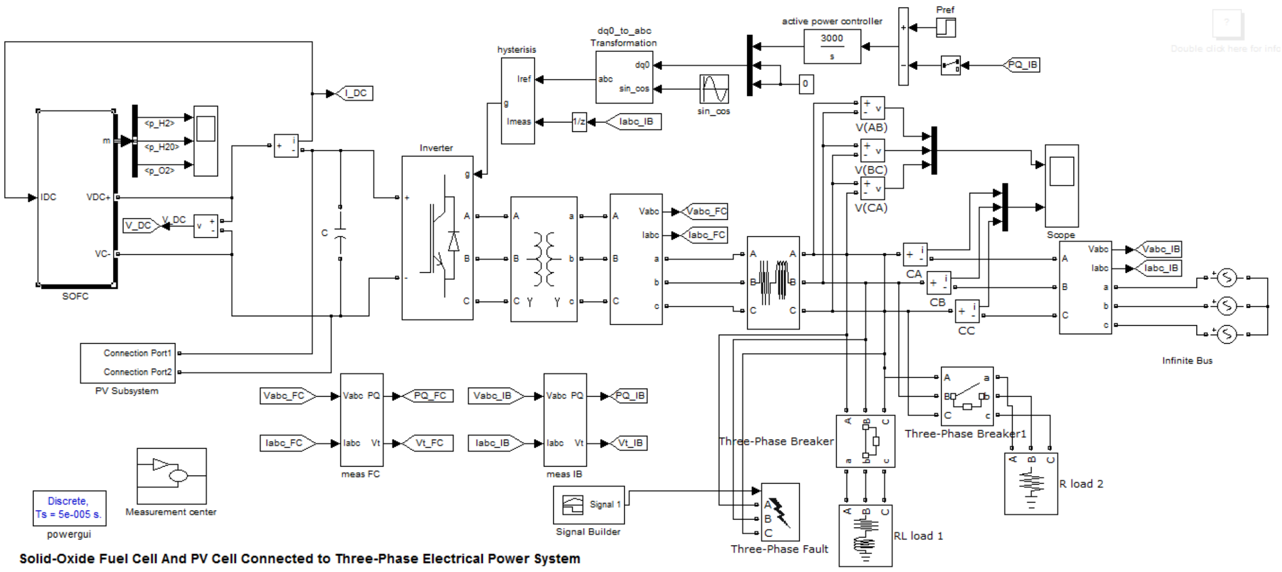

Fig: 1 SOFC and PV cell connecting 3-phase power system

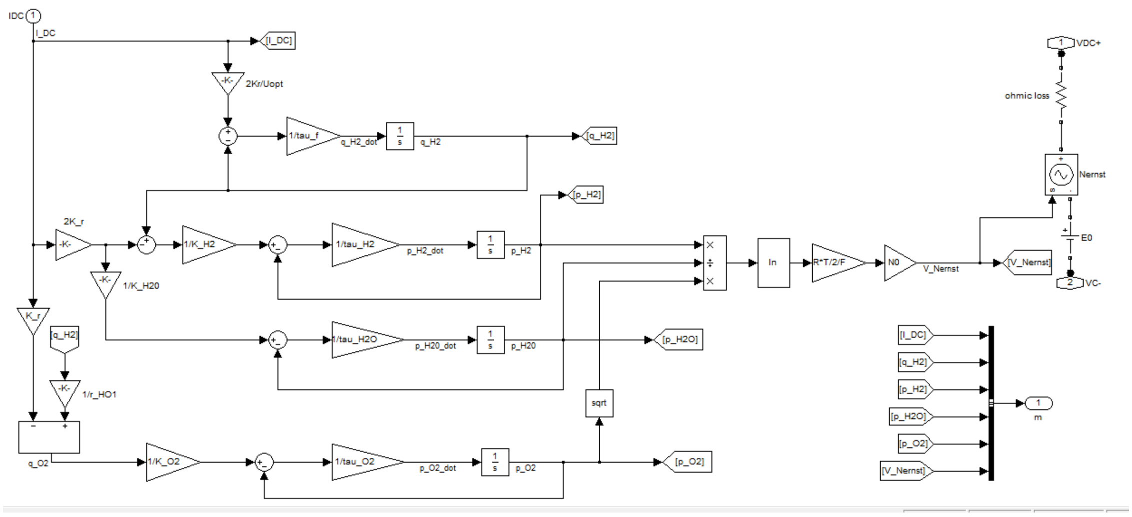

Fig: 2 Realization of SOFC Model

Today the critical situation of dwindling energy resources has risen which is mostly being faced by developing countries. There is a need to build a bridge in between power supply and energy demand to redress the constraint and to contribute in social and economic development. India is endowed with rich renewable energy resources and its immense potential must be utilized for making power supply much more accessible, affordable and reliable. The most popular way of power generation from solar energy is the application of PV technology or PV system. The inherent property of doped Silicon limits the efficiency of PV module within 15-20 %. Such a low efficiency of PV system and

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its high initial investment discourages users for PV system instalment thus making it as an unattractive renewable energy resource.

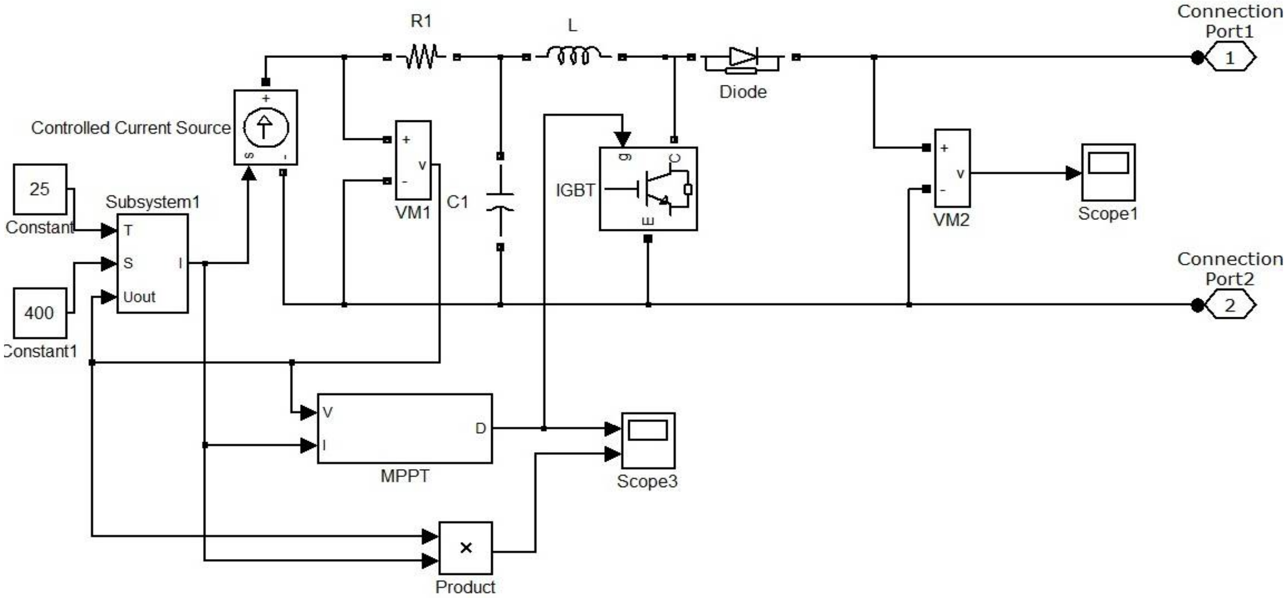

Fig 3. Simulink PV module

V. RESULT AND DISCUSSION

In this paper, the suggested Simulink model is stable because post fault voltage and current levels resume their respective normal levels. For minor fault conditions the system exhibits appreciable immunity and therefore the setup can be implemented with grid interconnection for adequate performance.

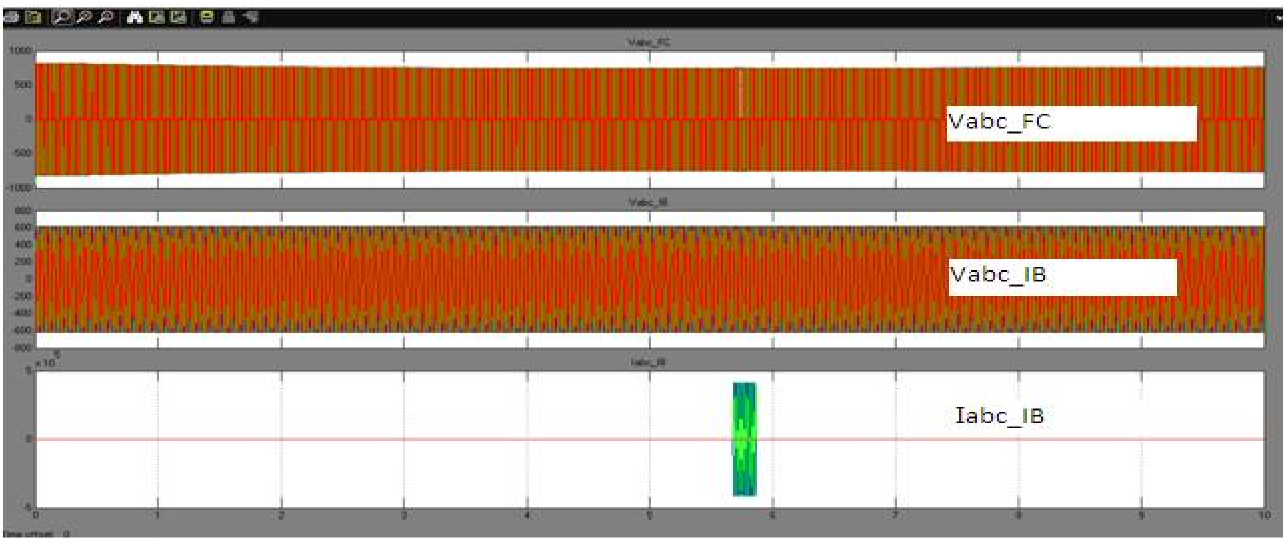

Fig: 4 Simulation of output V-I characteristic

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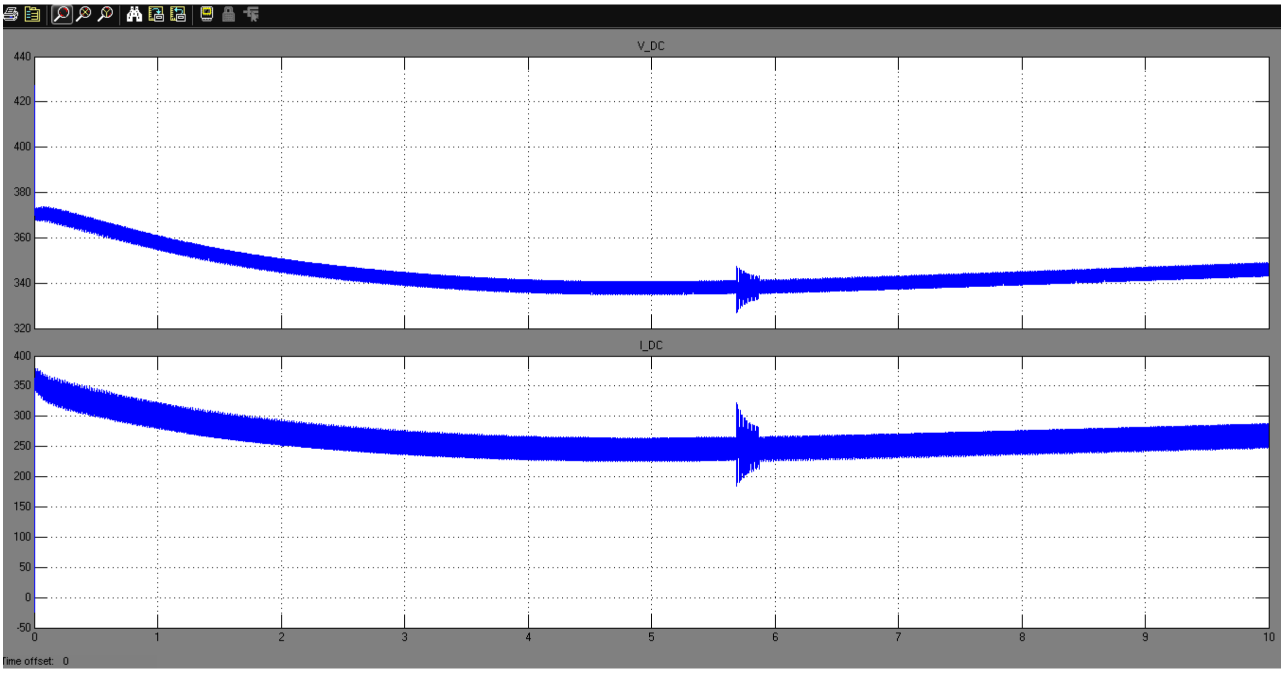

Fig: 5 Simulation results of DC voltage and current at the common DC link

V. CONCLUSION

Obviously, a complete hybrid power system of this nature may be too expensive and too labour intensive for many industrial technology departments; nevertheless such models have to be relied upon in near future for harnessing clean energy with minimum carbon footprints. The suggested model is more efficient and cheap as compared to present hybrid systems using BESS and can deliver more power to cater to Peak Load demands.

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