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Integration of Solar Power with Smart Grid

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Abstract—*Today's grid is outmoded (Most of the grids are designed and installed before the era of microprocessors) and suffering from reliability issues. The Grid control and optimization is modernized in a slow pace all around when compared to the pace of technology advancement. This is mainly due to the huge infrastructure investment involved. However, Smart Grid technologies are bringing the change very much needed in this area. Smart Grid provides two-way communication for electricity transmission and hence introduces the concept of demand prediction and controlled electricity generation. The benefits of smart grid can be enhanced through the integration of non-conventional energy sources like Solar, Wind and Biomass power plants.*
Solar power takes the prominent position among all other sources due to its continuous availability and cost effectiveness.
The main aim of the research work is to understand and outline Photovoltaic and Solar Power forecasting techniques in Smart Grid Energy Management. This research work also focuses on understanding concept and benefits of Smart Grid. The research work includes comprehensive literature survey to identify key findings in area of integration of Solar Power with Smart Grid Systems. As part of this research, role of Smart Grid to streamline the distributed solar power generation is outlined. Research work also aims to assess various ways of modeling and control of Smart Grid integration of Solar Energy conversion system, outlining the Solar PV requirements for Smart Grid applications,

1. INTRODUCTION TO SMART GRID

Innovation and modernization with new trends are being introduced in almost every field of science and technology. However, the power grid management across the world is not updated with the technology enhancement. Today's grid is outmoded (Most of the grids are designed and installed before the era of microprocessors) and suffering from reliability issues. The Grid control and optimization is modernized in a slow pace all around when compared to the pace of technology advancement. This is mainly due to the huge infrastructure investment involved. Now we are in the era of Smart Grid, hence lot of research and development activities in smart grid are under progress. The educational institutions and multinational companies are aggressively working on the smart grid concepts and non-conventional energy exploitation towards the green globe environmental cause for the future world. The core concept of smart grid is about integrating the Information Technology and Electrical utility for the benefit of consumers as well as industry.

"A smart grid is a system that is adaptive, interactive, secured, supports bi-directional energy flow and has no geographical or organizational boundaries"

Salient features of Smart Grid

- Intelligent Metering and better Reliability
- Improved Interoperability of appliances and equipment connected along with the infrastructure serving the Grid
- Better demand and response control deployment
- Active consumer participation by enabling control over consumption and associated costs over a wide network
- Distributed power generation and grid interaction from all sources of energy like Wind turbines, Solar panels and soon. Consumer engagement with resources to solve power crisis
- Environmentally friendly by maintaining the ratio of renewable generation to total generation and emission control With the implementation of smart grid technology, the penetration level of renewable may rise to 40%, demand-response to 20%, consumer generation increase tenfold, and generation, transmission and distribution asset utilization rise by about 30%-50%.

2. MODELING SMART GRID-CONNECTED PV HYBRID SYSTEM

2.1 Components: photovoltaic array, asynchronous (induction) generator, controller and converters.

2.2 Software Used: MATLAB/SIMULINK

The dynamic simulation model is described for photovoltaic hybrid generation system. The developed system consists of a photovoltaic array, dc/dc converter with an isolated transformer, designed for achieving the MPP with a current reference control (Iref) produced by P&O algorithm, asynchronous induction generator, and ac/dc thyristor controlled double-bridge rectifier. The block diagram of the developed system is shown in Fig.9.

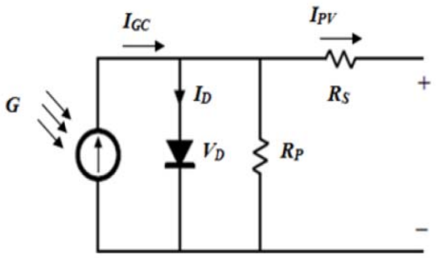

Fig 9: Single diode PV cell equivalent circuit

2.2.1 Solar cell model:

The circuit of the solar cell model, which consists of a photocurrent, diode, parallel resistor (leakage current) and a series resistor; is shown in Fig.9. According to both the PV cell circuit shown in Fig.9 and Kirchhoff's circuit laws, the photovoltaic current can be presented as follows [13]:

$$I_{pv} = I_{gc} - I_o\left[\exp^{\left(\frac{ev_d}{KFT_c}\right)} - 1\right] - \frac{v_d}{R_p}$$

Where Igc is the light generated current, Io is the dark saturation current dependent on the cell temperature, e is the electric charge = 1.6 x 10-19 Coulombs, K is Boltzmann's constant = 1.38 x 10-23 J/K, F is the cell idealizing factor, Tc is the cell's absolute temperature, vd is the diode voltage, and Rp is the parallel resistance. The photocurrent (Igc) mainly depends on the solar irradiation and cell temperature, which is described as below

$$I_{gc} = \left[\mu_{sc}\left(T_c - T_r\right) + I_{sc}\right]G$$

Where μsc is the temperature coefficient of the cell's short circuit current, Tref is the cell's reference temperature, Isc is the cell's short circuit current at a 25o C and 1kW/m2 , and G is the solar irradiation in kW/m2 . Furthermore, the cell's saturation current (Io) varies with the cell temperature, which is described as

$$I_o = I_{o\alpha}\left(\frac{T_c}{T_r}\right)^3 \exp^{\left[\frac{ev_g}{KF}\left(\frac{1}{T_r} - \frac{1}{T_c}\right)\right]}$$

$$I_{o\alpha} = \frac{I_{sc}}{\exp^{\left(\frac{ev_{oc}}{KFT_c}\right)}}$$

Where Ioα is the cell's reverse saturation current at a solar radiation and reference temperature, Vg is the band-gap energy of the semiconductor used in the cell, and Voc is the cells open circuit voltage.

2.2.2 Proposed model:

In this study, a general PV model is built and implemented using MATLAB/SIMULINK to verify the nonlinear output characteristics for the PV module. The proposed model is implemented, as shown in Fig. 4. In this model, whereas the inputs are the solar irradiation and cell temperature, the outputs are the photovoltaic voltage and current. The PV model's parameters are usually extracted from the manufactures data sheet.

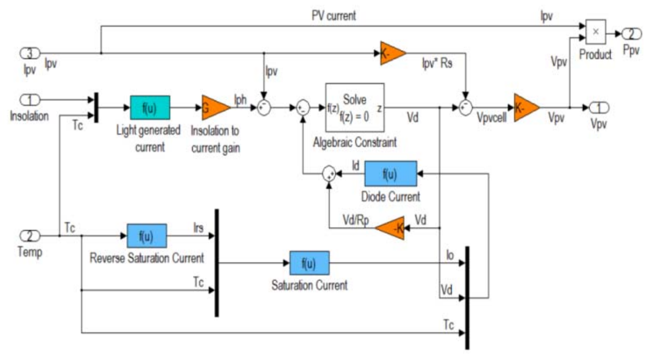

Fig 10: Subsystem implementation of PV model

2.3 Photovoltaic Control System:

The output characteristics of the PV model with different solar irradiance and cell temperature are nonlinear. Furthermore, the solar irradiation is unpredictable, which makes the maximum power point (MPP) of the PV module change continuously. Therefore, a maximum power point tracker (MPPT) technique is needed to operate the PV module at its maximum power point (MPP).

Perturb and observe (P&O) algorithm is the maximum power point tracker (MPPT) control algorithm that will be adapted in this model. The P&O algorithm operates by periodically incrementing or decrementing the PV array operating current, and comparing the PV output power with the previous one. If it is positive, the control system moves the PV array operating point in the same direction, else it moves in the opposite direction. A MPPT controller model is built and implemented using MATLAB, to operate the PV module at its maximum power point. The P&O algorithm requires two measurements: measurement of the current (Ipv) and measurement of the voltage (Vpv). The proposed model is implemented as shown in figure below

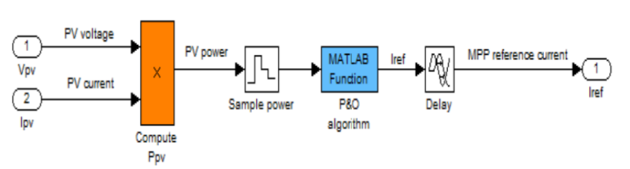

Fig 11: Subsystem implementation of the MPPT controller model

1.3.1 Switching model converter:

In addition, a dc averaged switched model converter with input current control (Iref) is built and implemented using MATLAB/SIMULINK, to reduce the switching harmonics and steps-up the photovoltaic voltage to a higher dc voltage (e.g. 400V). The proposed model is implemented as shown in Fig.12.

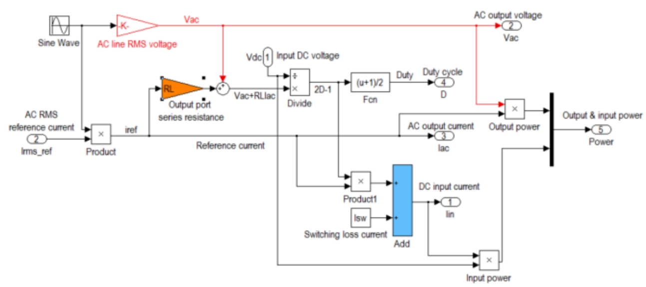

Fig 12: Subsystem implementation of the dc/ac inverter model

2.3.2 Automatic feedback controller :

However, when the PV system with a MPPT is connected to the power electronic converters (PEC), an automatic feedback controller will be needed to balance the power and maintain the direct voltage constant; especially when the system is running under various conditions. The proposed PV control system model is implemented as shown in Fig. 13.

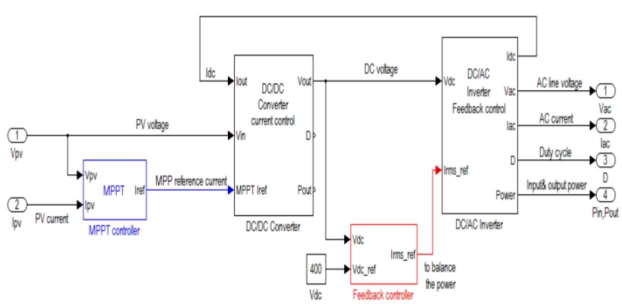

Fig 13: Implementation of PV Control System Model

The major inputs for the proposed PV model were solar irradiation, PV panel temperature and PV manufacturing data sheet information's. In this study, Astronergy CHSM6610P PV panel is taken as example. The block diagram is shown below

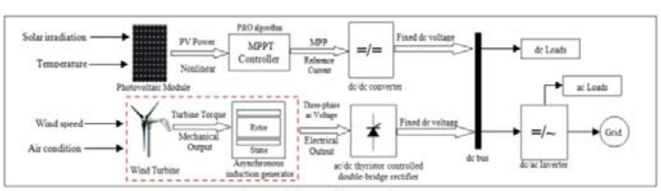

Fig 14: Block diagram of proposed system

2.3.3 Simulation result :

The I-V and P-V output characteristics for the PV model are shown in Fig.14. The output power and current of PV module depend on the solar irradiance and temperature, and cell's terminal operating voltage as well. It was found from Fig. 15(a) and Fig. 15(b) that with increased solar irradiance there is an increase in both the maximum power output and the short circuit current. On the other hand, we observe from Fig. 15(c) and Fig 15(d) and that with an increase in the cell temperature the maximum power output decreases whilst the short circuit current increases.

3. PROPOSED MODEL RESULT

The objective of the P&O algorithm is to adjust the dc/dc control variable (Iref), so that the PV array operates at the maximum power point (MPP). And that done, by periodically incrementing or decrementing the PV array operating current (Ipv = Iref)

A novel PV/WT hybrid power system is designed and modeled for smart grid applications. The developed algorithm comprises system components and an appropriate power flow controller. The model has been implemented using the MATLAB/SIMULINK software package, and designed with a dialog box like those used in the SIMULINK block libraries. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system. The developed system and its control strategy exhibit excellent performance for the simulation of a complete day. The proposed model offers a proper tool for smart grid performance optimization.

4. CONCLUSION

System operators and energy planners must overcome several challenges when integrating high penetrations of variable Solar Energy. These challenges can be roughly grouped as either technical or economic, policy, and regulatory in nature. Solutions to four specific challenges are emerging, and will be important to watch in coming years:

- Managing variability and uncertainty during the continuous balancing of the System
- Balancing supply and demand during generation scarcity and surplus situations
- Deferring or avoiding capital-intensive grid upgrades
- Enhancing Solar Energy project returns to enhance the investment environment.

Fortunately, there already exist a variety of potential technology and practical solutions that can be used to overcome these challenges, such as improved forecasting, smart inverters, demand response, storage (distributed and large-scale), real-time system awareness, and dynamic line rating. New advanced energy management protocols in the transmission and distribution operator interfaces can also support flexible integration of variable Solar Energy.

In this research work we assessed the concept of Smart Grid and how it can enable more reliable and predictable Solar Power generation. We also identified methods to forecast demand and explored the concepts of micro inverter and required modeling to simulate certain scenarios.

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