MODELLING AND SIMULATION OF PV/HYDRO HYBRID SYSTEM USING P-Q THEORY

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ABSTRACT

Electrical energy requirements for many remote applications are too large to allow the cost effective use of stand-alone or autonomous PV systems. In these cases, it may prove more feasible to combine several different types of power sources to form what is known as a "hybrid" system. Hybrid systems can be designed to maximize the use of renewable, resulting in a system with lower emissions than traditional fossil-fuel technologies. This paper presents the modelling and simulation of renewable energy hybrid system inter connected to the electrical utility. PV/hydro HEPS, taking into account all radiation, temperature, HYDRO speeds and variation of the load demand during the day. The model is developed in MATLAB/SIMULINK environment in order to simulate all quantities of HEPS such as AC output current of the inverter that injected to the load/grid, load current, grid current. It also simulates power output from PV and HTG, power delivered to or from grid and finally power factor of the inverter for PV, HTG and grid. The present circuit uses hysteresis current control and instantaneous p-q (real-imaginary) power theory.

Keywords: PV System, PV/hydro HEPS, MPPT, HTG and grid, P-Q Theory.

1. INTRODUCTION

As energy demands around the world increases the need for a renewable energy source that will not harm the environment has been increased. Some projections indicate that the global energy demand will almost triple by 2050. Renewable energy source currently supply somewhere between 15% and 20% of total world energy demand. PV and hydro energy system, HES, are the most promising as a future energy technology. A 30% contribution to world energy supply from renewable energy source by year 2020 would reduce the energy related CO2 emission by 25%. D.Hansen et.al. Presented a number of models for modeling and simulation of stand-alone PV system with battery bank verified against a system installed at Ris national laboratory. The implementation has been done using Matlab/Simulink. Hang-seok Choi, et.al. Presented a new zero current switching for grid connected PV system. The proposed circuit provides zero current switching condition for all the switches, which reduces switching losses significantly. It is controlled to extract maximum power from the solar array and to provide sinusoidal current into the electrical utility. Gregor P. Henze, et.al. Investigated an adaptive optimal control of a grid independent PV system consisting of a controller, storage, and a load. Francs turbines are most widely used among water turbines and the development of the Francis turbines in the last decade has opened up a large range of new application possibilities for this type. These advances, motivated by a search for maximum profitability, have become possible as the result of improved knowledge of the water flows in turbines and other hydraulic phenomena. Koch F., et. al. described the effect of large HYDRO parks on the frequency of the interconnected system on which they are operating. Additionally, the effect of the landscape and atmospheric condition at the location of the HYDRO unit on the output power incorporated into the simulation. With increased penetration of WES various researches for modeling of WTG connected to the EU developed. Debra J. Lew et. Al presented a designed hybrid HYDRO/photovoltaic systems, using batteries for households in Inner Mongolia using the optimization program HOMER and model Hybrid2. R. Chedid and Saifur Rahman introduced a decision support technique for design of PV/HEPS. The developed PV/HEPS composed of four design variables: (HTG's), PV arrays, batteries and grid-linked substations. The design of a PV/WES HEPS based on political and social conditions and uses trade-off/risk method. The Decoupled PV/HEPS discussed, control and management strategies that applied to a simulation model of an example of this type presented. Yarú Najem and Méndez Hernández simulation models of the PV/HEPS verified with measured data in a real system located near the department efficient energy conversion of the Kassel University. But most of the researches haven’t modeling and simulation of PV/HYDRO HEPS at the point of connection of operation in details. So, the objective of this paper is to present modeling, simulation, design and analysis DC/AC converter and its controller for PV/HYDRO HEPS.

2. HYBRID POWER SYSTEMS

Hybrid power systems combine two or more energy conversion devices, or two or more fuels or the same device, that when integrated, overcome limitations inherent in either. Hybrid systems can address limitations in terms of fuel flexibility, efficiency, reliability, emissions and / or economics. Hybrid systems can be designed...
to maximize the use of renewable, resulting in a system with lower emissions than traditional fossil-fueled technologies. Electrical energy requirements for many remote applications are too large to allow the cost-effective use of stand-alone or autonomous PV systems. To date, PV has been effectively combined with other types of power generators such as hydro, thermoelectric, petroleum-fueled and even hydrogen. The selection process for hybrid power source types at a given site can include a combination of many factors including site topography, seasonal availability of energy sources, cost of source implementation, cost of energy storage and delivery, total site energy requirements, etc. Hybrid power systems use local renewable resource to provide power. Village hybrid power systems can range in size from small household systems (100 Wh/day) to ones supplying a whole area (10’s MHz/day). They combine many technologies to provide reliable power that is tailored to the local resources and community. Potential components include: PV, HYDRO, micro-hydro, river-run hydro, biomass, batteries and conventional generators.

2.1. Other PV/hybrid types
Certain specific site locations may offer access to other forms of power generation. Access to flowing water presents the potential for hydro power. Access to consistent HYDRO at sufficient velocity presents the potential for HYDRO power. PV/hydro and PV/HYDRO hybrid systems have been utilized at sites with daily energy requirement ranges similar to those described for PV/genset hybrids. Their use, however, is much more site dependent, as their energy source is a factor of that locations’ topography. PV/Thermoelectric generator hybrid systems have been used effectively at sites whose daily energy requirement is relatively low, ranging from 1 to 20 kWh per day.

2.2. PHOTOVOLTAICS
Photovoltaic technology involves the direct conversion of sunlight into electricity through the use of photovoltaic (PV) modules. Solar cells (or photovoltaic cells) are composed mainly of silicon (Si). Certain conditions electrons from silicon atoms can be and become available to move as part of an electric current. When solar cells are joined physically and electrically and placed into a frame they form a solar panel or PV module (Figure 3). Panels joined together form a solar array. A typical module of 1 m² would be able to produce around 100W. Commercial PV systems are about 7% to 17% efficient.

2.3. MAXIMUM POWER POINT TRACKING (MPPT)
MPPT algorithm, name itself uses for maximum power absorbing from its relevant sources. Here, i.e., MPPT is used to grab the power from both PV and HYDRO systems. The main principle of MPPT is it will grab the maximum power from one system whenever the other system performance or power availability is low. In this project the value of MPPT will change whenever the changes in PV system. (i.e., mainly in the night times and rainy seasons). Mainly MPPT algorithms will co-ordinate the different power sources. In this project MPPT block, we are measuring power by multiplying the voltage and current blocks, and we r giving these power to switches at different instances by using unit delay block. Finally we are giving these powers as pulses to IGBT (i.e, mppt block output).

Maximum power point tracking is a technique that solar inverters use to get the most possible power from the PV array. Any given PV module or string of modules will have a maximum power point: essentially, this defines current that the inverter should draw from the PV in order to get the most possible power (power is equal to voltage times current). A maximum power point tracker (or MPPT) is a high efficiency DC to DC
converter that presents an optimal electrical load to a solar panel or array and produces a voltage suitable for the load.

![Solar Cell I-V Curve](image)

**FIG. 2:** I-V Curve for a Solar Cell

3. **P-Q THEORY POWER COMPONENTS**

The p-q theory implements a transformation from a stationary reference system in a-b-c coordinates, to a system with co-ordinates α-β-0. It corresponds to an algebraic transformation, known as Clarke transformation, which also produces a stationary reference system, where coordinates α-β are orthogonal to each other, and coordinate 0 corresponds to the zero-sequence component.

The zero sequence calculated here differs from the one obtained by the symmetrical components transformation, or Fortescue transformation, by a factor. The voltages and currents in α-β-0 coordinates are calculated as follows:

\[
\begin{bmatrix}
    v_o \\
    v_a \\
    v_b \\
    v_c \\
\end{bmatrix}
= T
\begin{bmatrix}
    v_0 \\
    v_a \\
    v_b \\
    v_c \\
\end{bmatrix}
\]  

(1)

\[
\begin{bmatrix}
    i_o \\
    i_a \\
    i_b \\
    i_c \\
\end{bmatrix}
= T
\begin{bmatrix}
    i_0 \\
    i_a \\
    i_b \\
    i_c \\
\end{bmatrix}
\]  

(2)

Where,

\[
T = \frac{1}{\sqrt{3}} \begin{bmatrix}
1 & 1 & 1 \\
\sqrt{2} & \sqrt{2} & \sqrt{2} \\
1 & -1 & -1 \\
\sqrt{3} & -\sqrt{3} & 0 \\
\end{bmatrix}
\]  

(3)

The p-q theory power components are then calculated from voltages and currents in the α-β-0 coordinates. Each component can be separated in its mean and alternating values (see Fig. 1), which present physical meanings:

**Instantaneous Zero-Sequence Power (p0)**

\[
P_0 = v_o \cdot i_o = \bar{P}_0 + \tilde{P}_0
\]  

(4)

\(P_0\) - Mean value of the instantaneous zero-sequence power. It corresponds to the energy per time unity that is transferred from the power source to the load through the zero-sequence components of voltage and current.

\(\tilde{P}_0\) - Alternating value of the instantaneous zero-sequence power. It means the energy per time unity that is exchanged between the power source and the load through the zero-sequence components of voltage and current.

The zero-sequence power exists only in three-phase systems with neutral wire. Moreover, the systems must have both unbalanced voltages and currents, or the same third m order harmonics, in both voltage and current, for at least one phase. It is important to notice that \(\tilde{P}_0\) cannot exist in a power system without the presence of \(\bar{P}_0\). Since \(\bar{P}_0\) is clearly an undesired power component (it only exchanges energy with the load, and does not transfer any energy to the load), both \(\bar{P}_0\) and \(\tilde{P}_0\) must be compensated.
**Instantaneous Real Power** (\( p \))

\[
p = v_a i_a + v_b i_b = \bar{p} + \tilde{p}
\]  \( (5) \)

- Mean value of the instantaneous real power. It corresponds to the energy per time unity that is transferred from the power source to the load, in a balanced way, through the \( a-b-c \) coordinates (it is, indeed, the only desired power component to be supplied by the power source).

- Alternating value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load, through the \( a-b-c \) coordinates. Since \( \tilde{p} \) does not involve any energy transference from the power source to load, it must be compensated.

**Instantaneous Imaginary Power** (\( q \))

\[
q = v_{\beta} i_a - v_a i_{\beta} = \bar{q} + \tilde{q}
\]  \( (6) \)

- Mean value of instantaneous imaginary power.

- Alternating value of instantaneous imaginary power.

The instantaneous imaginary power, \( q \), has to do with power (and corresponding undesirable currents) that is exchanged between the system phases, and which does not imply any transference or exchange of energy between the power source and the load.

Rewriting equation (4) in \( a-b-c \) coordinates the following expression is obtained:

\[
q = \left( (v_a - v_b) i_c + (v_b - v_c) i_a + (v_c - v_a) i_b \right) / \sqrt{3}
\]  \( (7) \)

This is a well known expression used in conventional reactive power meters, in power systems without harmonics and with balanced sinusoidal voltages. These instruments, of the electro-dynamic type, display the mean value of equation (5).

The instantaneous imaginary power differs from the conventional reactive power, because in the first case all the harmonics in voltage and current are considered.

In the special case of a balanced sinusoidal voltage supply and a balanced load, with or without harmonics, the mean value of equation (5) is equal to the conventional reactive power (\( \bar{q} = 3 \cdot V \cdot I_1 \cdot \sin(\phi) \)).

**Fig.3: P-Q Theory Power Components**

It is also important to note that the three-phase instantaneous power (\( p3 \)) can be written in both coordinates systems, \( a-b-c \) and \( \alpha-\beta-0 \), assuming the same value:

\[
p_3 = v_a \cdot i_a + v_b \cdot i_b + v_c \cdot i_c = p_a + p_b + p_c \quad \text{............... \( (8) \)}
\]

\[
p_3 = v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta + v_0 \cdot i_0 = p + p_0 \quad \text{............... \( (9) \)}
\]

Thus, to make the three-phase instantaneous power constant, it is necessary to compensate the alternating power components \( \tilde{p} \) and \( \tilde{p}_0 \). Since, as seen before, it is not possible to compensate only \( \tilde{p}_0 \), all zero-sequence instantaneous power must be compensated.

Moreover, to minimize the power system currents, the instantaneous imaginary power, \( q \), must also be compensated. The compensation of the p-q theory undesired power components (\( \tilde{p} \), \( p_0 \) and \( q \)) can be
accomplished with the use of an active power filter. The dynamic response of this active filter will depend on the time interval required by its control system to calculate these values.

4. MATLAB/SIMULINK SOFTWARE:
MATLAB® is a high-level language and interactive environment that enables you to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN. We can use MATLAB in a wide range of applications, including signal and image processing, communications, control design, financial modeling and analysis. Add-on toolboxes (collections of special-purpose MATLAB functions) extend the MATLAB environment to solve particular classes of problems in these application areas. MATLAB provides a number of features for documenting and sharing your work. You can integrate your MATLAB code with other languages and applications, and distribute your MATLAB algorithms and applications. Simulink® is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing.

5. MATLAB BLOCK DIAGRAM OF PV/HYDRO HYBRID POWER SYSTEM

6. RESULTS

![Simulated of the Load Line Current in the side (C)](image)

![Simulated of the Generated Power from PV/HTG, Load Demand and Grid Power](image)
CONCLUSIONS
A novel of PV/HYDRO HEPS interface with EU for solving modelling and simulation problems by using Matlab/Simulink environment have been developed. Detailed modelling, simulation and control of a DC/AC converter connected to EU have been developed. A simulation of any PV/HYDRO interconnected to EU. By using this computer program the interface between hybrids PV/HYDRO interconnected with EU can be designed, modelled and simulated. This computer program has been applied on modelling and simulation of a specified PV/HYDRO interconnected with EU power plant.

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