ENERGY MANAGEMENT IN PV-BATTERY-HYDRO MICRO-GRID USING FUZZY LOGIC CONTROLLER

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ABSTRACT

This paper mainly deal with the Energy Management System of the micro-grid system which was fed with the hybrid power generation system consists of frequency regulation, voltage regulation, power management and load leveling of solar photovoltaic (PV)-battery-hydro based micro-grid (MG). In this MG, the battery capacity is reduced as compared to a system, where the battery is directly connected to the DC bus of the voltage source converter (VSC). A bidirectional DC–DC converter connects the battery to the DC bus and it controls the charging and discharging current of the battery. It also regulates the DC bus voltage of VSC, frequency and voltage of MG. The proposed system manages the power flow of different sources like hydro and solar PV array. However, the load leveling is managed through the battery. The battery with VSC absorbs the sudden load changes, resulting in rapid regulation of DC link voltage, frequency and voltage of MG. Therefore, the system voltage and frequency regulation allows the active power balance along with the auxiliary services such as reactive power support, source current harmonics mitigation and voltage harmonics reduction at the point of common interconnection. The experimental results under various steady state and dynamic conditions, exhibit the excellent performance of the proposed system and validate the design and control of proposed MG. The Energy Management System incorporates the fuzzy logic control, which was used to achieve the optimization and distributed energy generation. The main operation of the Energy Management System is that committing the energy sources, and battery management. In the case of the battery management the fuzzy control the State of Charge (SoC) parameters of the battery. The proposed fuzzy logic based controller (FLC). The power fluctuation is suppressed and supply a good quality power while maintaining SOC within limits.

INTRODUCTION

Due to the rapid depletion of fossil fuel and environment pollution people are now attracted towards non conventional energy sources like PV, wind, hydro etc. Solar and wind energy resources are abundantly available all over the world. For the fluctuating nature of renewable energy resources power generation from renewable energy systems are intermittent. These circumstances motivated to combine two or more energy sources with storage system to make Hybrid Renewable Energy System. An isolated hybrid system gives a higher efficiency with a low cost of energy production, compared to the system with a single source. It is necessary to take care of changes in the generated power which is varying from time to time. In literature different types of HRES are introduced which are working in grid connected or stand-alone mode. HRES system energy management is done by using PI controller. It is done by controlling a buck-boost bidirectional converter for battery charging and discharging. A current control strategy for power balance is presented by PI controller in. The conventional controller design depends on mathematical modeling of the system. For complex system the mathematical model cannot be properly defined. In spite of all the system parameters are known, there may be parameter variations during the operation of the system. So it is difficult to design controller parameters and more time is required. Many researchers are worked with
latest controllers such as predictive controller, sliding mode controller, H-infinity controller for better steady state and transient response of systems. These control techniques depend on complex mathematical analysis. In order to avoid the difficulties in controller designing, intelligent controllers are used. For better results intelligent controller are now applied in various hybrid energy system problems. An application of FLC for inverter voltage and frequency control is. FLC works very well even after variations in system parameter and operating conditions. Here a fuzzy logic based controller for battery charging or discharging is proposed and implemented for system power flow control to suppress the power fluctuation and to supply a quality power to load.

In the present scenario, the proliferation of energy demand of households and industries, create challenges and set a limit on the power generation from the conventional energy sources. The solution to this problem lies somewhere in the core of power generation through renewable energy sources (RES), with efficient, cost effective and reliable generation through RES. The rural electrification is provided by a standalone diesel generator and an integration of other RES. However, the setback for this technology is an RES intermittent nature. This leads to the component over sizing while designing any hybrid renewable energy based microgrid (MG). This also increases the initial cost, operational cost, and life cycle cost. These shortcomings open the window for hybridisation of RES to back up each other. However, this requires the optimal integration of RES and various types of hybrid systems. Philip et al. have demonstrated the diesel engine driven generator, battery and photovoltaic (PV) array based hybrid standalone MG. Due to increasing fuel prices and increased pollution concerns, the diesel PV based MG has limited scope. Moreover, the topology presented in the literature has the battery directly connected to the direct current (DC) link. Due to this, the battery is exposed to direct DC link voltage fluctuations. This reduces the battery life. In the proposed topology, the battery is connected to the DC-link through a bidirectional DC–DC converter (BDDC). Hence second harmonic current is eliminated from the battery current. Grid connected RES are another class of topologies, which are available in the literature. These topologies based MGs are possible at those places, where grid availability is easy. However, the proposed topology is also possible in rural areas. Merabet et al. and Prakash et al. have reported the wind, PV and battery based MG. They have established the control algorithm to look after the power compatibility and power management among different RES in the MG. Wind and PV both being of intermittent nature, present a problem to the optimal sizing of the energy storage. The minimum required battery size, depends on the critical load that the MG must be capable of feeding when both the solar and wind, are unavailable. In this way, the storage may be oversized. However, in the proposed MG, hydro also supports the critical load, thus the battery size is reduced. Moreover, initial and operational costs, are low and maintenance requirement is also less.

The small hydro power plant in remote regions is recognised as a promising energy source to generate electricity. The small hydro system up to 100 kW rating does not require governor control based turbine prime mover and curtails down the cost of the turbine. The generator used in the small hydro has many variations. Synchronous generator, permanent magnet synchronous generator synchronous reluctance generator and self-excited induction generator (SEIG) are some of them. However, the most cost effective, efficient, rugged, and easy to use generator in the small hydro system is SEIG. Additionally, the maintenance requirement is also less as compared with its synchronous counterpart. Moreover, SEIG has the drawback that it demands reactive power or magnetising current for producing the desired terminal voltage. Therefore, an excitation capacitor bank provides magnetising current for regulating the terminal voltage of the generator. The hydro-based generating system operates in almost constant power mode so that if the load changes, the frequency, and voltage also changes from their reference values.

In this system, PV-battery-hydro based MG is designed for low voltage, which supplies power to small pockets of customers. The proposed MG consists of two energy sources namely hydro and PV with BES. The hydro-based MG adds stiffness and inertia to the system voltage and also increases the
reliability of the MG as compared with the wind based MG. An integration of BES eliminates the need for a dump load and adds to the functionality of the MG. This BES is controlled by a bidirectional converter, which reduces the capacity of storage and utilises the battery effectively. Moreover, BES maintains the continuity of the supply in varying load conditions. The generation of stable, maximum and continuous energy from the PV array is achieved through incremental conductance (INC) maximum power point tracking (MPPT) technique [26]. Additionally, some ancillary services are achieved like current harmonics mitigation, voltage harmonics reduction and reactive power support at the point of common interconnection (PCI). The VSC switching is based on the synchronous reference frame (SRF) theory. Therefore, the proposed standalone PV hydro based MG is highly suitable to serve the remote places where electrification is either not yet done or the cost of the electrification is costly.

**Structure and design of proposed MG**

The proposed MG consists of two SOURCES namely hydro, solar PV array along with a BES, a boost converter for MPPT operation and a BDDC for the battery control, as shown in Fig. 1a. A SEIG is used as a hydro generator, which is driven by an unregulated turbine operating in the constant power region. A VSC is connected to the PCI through the coupling inductors. The battery shares the common DC bus of the VSC through the BDDC and solar PV system is also connected to the DC bus of the VSC through the boost converter. Moreover, the ripple filter, linear and non-linear loads are connected to the PCI. The hardware implementation of the proposed MG is done using the digital processor (dSPACE-1103). The inputs of the digital processor are PCI voltages, load currents, source currents, battery current, sensed DC bus voltage, solar PV voltage, and current. However, these parameters are sensed using the Hall-effect voltage and current sensors. After this, the digital processor reads these sensed data via analog to digital converter (ADC) and processes according to the SRF based control algorithm and generates the switching pulses for the VSC.

**FIG 1:** Proposed PV-battery-hydro MG,

**Design of battery and ripple filter**

Based on the total capacity of the hydro and solar PV array, the energy storage system capacity is selected. In case, the load is isolated from the MG, the battery should be able to take the whole generated power of the hydro and solar PV array. Moreover, in this extreme operating condition, the battery should regulate the frequency and voltage of the MG. Hence, the battery rating is selected as 240 V, 14 Ah. The ripple filter is designed to suppress the high-frequency noise caused by the switching the VSC. The ripple filter is a low pass filter and it is the series combination of the capacitor and resistance and their values, are selected as 10 μF and 5 Ω.

**Design of bidirectional converter**

The bidirectional DC-DC inductor (BDDC), which connects the battery to the DC bus, is designed to operate as a buck converter while charging the battery and operates as a boost converter in the battery discharging mode. This inductor of the BES is designed as, For buck mode operation of the bidirectional converter, filter inductor of the battery is designed as duty cycle ($D$) = $V_b/V_{dc} = 240/360 = 0.66$.

**Control strategy for VSC**

The VSC control is based on an indirect current control algorithm in which VSC switching is based on reference source currents ($i_{sa}$, $i_{sb}$, $i_{sc}$) as shown in Fig. 2a. This control algorithm is subdivided into several parts like estimation of the angle between fixed and rotating frames, estimation of real and reactive components of load currents,
determination of reference source currents and switching of VSC.

FIG:2 Control algorithm for VSC,

FIG:3 Control diagram of standalone MG
(b) Estimation of \(\sin \theta\) and \(\cos \theta\) components, (c) Controller for BDDC

FUZZY LOGIC CONTROLLER

Fuzzy logic control mostly consists of three stages:
a) Fuzzification
b) Rule base
c) Defuzzification

During fuzzification, numerical input variables are converted into linguistic variable based on a membership functions. For these MPP techniques the inputs to fuzzy logic controller are taken as a change in power w.r.t change in current E and change in voltage error C. Once E and C are calculated and converted to the linguistic variables, the fuzzy controller output, which is the duty cycle ratio D of the power converter, can be search for rule base table. The variables assigned to D for the different combinations of E and C is based on the intelligence of the user. Here the rule base is prepared based on P&O algorithm.

In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function.

MPPT fuzzy controllers have been shown to perform well under varying atmospheric conditions. However, their influence depends a lot on the intelligence of the user or control engineer in choosing the right error computation and coming up with the rule base table. The comparison for error E and change in code C are given as follows:

\[
E = \frac{P(K) - P(K - 1)}{I(K) - I(K - 1)}
\]

\[
C = V(K) - V(K - 1)
\]

The general structure of a complete fuzzy control system is given in Figure 9. The plant control ‘u’ is inferred from the two state variables, error (e) and change in error (\(\Delta e\)) The actual crisp input are approximates to the closer values of the respective universes of its course. Hence, the fuzzy fied inputs are described by singleton fuzzy sets. The elaboration of this controller is based on the phase plan. The control rules base are designed to assign a fuzzy set of the control input u for each combination of fuzzy sets of e and \(\Delta e\). The Table 1 is as shown in below:

Figure
Here, NL=Negative Large
NM=Negative Medium
NS=Negative Small
Z=Zero
PS=Positive Small
PM= Positive Medium
PL= Positive Large

Fuzzy is more advantageous than PI controller because of its faster response. The operation of fuzzy logic is much simpler when the fault occurs at the source due to its rule during the type of fault obtained in the source voltage, need less space to establish and finally most important thing we have to concern it is very less in cost compared to PI controller.

EXTENSION FUZZY

**Table 1. Fuzzy Rules**

<table>
<thead>
<tr>
<th>Act</th>
<th>NL</th>
<th>NM</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PM</th>
<th>PL</th>
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<tbody>
<tr>
<td>NL</td>
<td>PL</td>
<td>PL</td>
<td>PL</td>
<td>PL</td>
<td>NM</td>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>NM</td>
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<td>NM</td>
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</table>

**Fig 5:** Fuzzy input and output windows

**Fig 6:** Dynamic performance of PV-battery-hydro based MG following by solar irradiance change (c) vsab, isa, iLa and ivsca, (d) Vdc,Ipv,Vb and Ib
Fig. 7 Dynamic performance of hydro-battery-PV based MG under load perturbation (a) vsab, isc,Ipv and ivscc, (b) Vdc, Ipv, Vb and Ib.

Fig:8 Source voltage THD

Fig9: Load current THD

Compare both pi and FUZZY:

<table>
<thead>
<tr>
<th>SOURCE VOLTAGE THD%</th>
<th>LOAD CURRENT THD%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI</td>
<td>0.8%</td>
</tr>
<tr>
<td>FUZZY</td>
<td>0.79%</td>
</tr>
</tbody>
</table>

Conclusion

In the proposed MG, an integration of hydro with the battery, compensates the intermittent nature of PV array. The proposed system uses the hydro, solar PV and battery energy to feed the voltage (Vdc), solar array current (Ipv), battery voltage (Vb) and battery current (Ib). When the load is increased, the load demand exceeds the hydro generated power, since SEIG operates in constant power mode condition.
This system has the capability to adjust the dynamical power sharing among the different RES depending on the availability of renewable energy and load demand. A bidirectional converter controller has been successful to maintain DC-link voltage and the battery charging and discharging currents. Experimental results have validated the design and control of the proposed system and the feasibility of it for rural area electrification.

Fuzzy logic control based maximum power point tracking (MPPT) approach is used to improve the efficiency and robustness of the solar photovoltaic (PV) power generation and establishes a model of grid-connected PV system by Matlab/Simulink environment which reflect the characteristics of the system accurately. We are using battery for energy storage purpose. It gives continuous power, compelling use of renewable energy resources. It enhances life time of battery, minimized utilization of diesel and reduces the emission of CO2. Fuzzy logic based system is more effective, energy management controller controls hybrid power system to provide uninterrupted power, minimizing usage of diesel, effective utilization of sources. Since the usage of diesel generator is minimized emission of harmful gases from it is minimized.

References


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