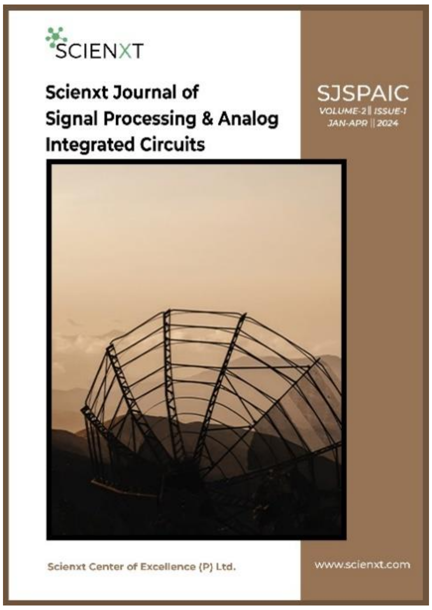

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Result and analysis of microgrid based on wind driven DFIG and boost converter with PV array for optimal fuel consumption

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Abstract:

In this Paper a micro grid is introduced with PVA and battery connected to DFIG for energy sharing. This paper presents a green energy solution to a microgrid for a location dependent on a diesel generator (DG) to meet its electricity requirement. This microgrid is powered by two renewable energy sources namely wind energy using doubly fed induction generator (DFIG) and solar photovoltaic (PV) array. The solar PV array is directly connected to common DC bus of back- back voltage source converters (VSCs), which are connected in the rotor side of DFIG. Moreover, battery energy storage (BES) is connected at same DC bus through a bidirectional buck/boost DC- DC converter to provide path for excess stator power of DFIG. The extraction of maximum power from both wind and solar, is achieved through rotor side VSC control and bidirectional buck/boost DC-DC converter control, respectively. Moreover, the control of load side VSC, is designed to optimize the fuel consumption of DG. A novel generalized concept is used to compute the reference DG power output for optimal fuel consumption. The microgrid is modelled and simulated using Sim Power Systems tool box of MATLAB, for various scenarios such as varying wind speeds, varying insolation, effect of load variation on a bidirectional converter and unbalanced nonlinear load connected at point of common coupling (PCC). The DFIG stator currents and DG currents, are found balanced and sinusoidal. The model is further updated with DC-DC boost converter connected to PVA for maximum power extraction controlled by MPPT algorithm. A comparative analysis is carried out with power delivered from the module to the grid for the two modules.

Keywords:

Wind Turbine, doubly fed induction generator (DFIG), diesel generator, solar photovoltaic array, bidirectional buck/boost DC-DC converter, battery energy storage, power quality.

1. Introduction:

Microgrids are emerging as an integral feature of the future power systems shaped by the various smart-grid initiatives. A microgrid is formed by integrating loads, distributed generators (DG) and energy storage devices. Microgrids can operate in parallel with the grid, as an autonomous power island or in transition between grid-connected mode and islanded mode of operation.

The microgrid concept, involving small transmission and distribution (T&D) networks, efficiently makes use of all the location specific distributed generations (DGs) and distributed energy resource (DERs). These are self-sustained power systems mainly based on loads fed through radial distribution systems and can operate either interconnected to the main distribution grid, or even in isolated mode.

The microgrids advantages are as follows: i) provide good solution to supply power in case of an emergency and power shortage during power interruption in the main grid, ii) plug and play functionality is the features for switching to suitable mode of operation either grid connected or islanded operation, provide voltage and frequency protection during islanded operation and capability to resynchronize safely connect microgrid to the grid , iii) can independently operate without connecting to the main distribution grid during islanding mode, all loads have to be supplied and shared by distributed generations. Microgrid allows integration of renewable energy generation such as photovoltaic, wind and fuel cell generations. After implementation, all the advantages of a microgrid may not become apparent right away because of higher cost of energy as compared to the cost of grid power.

1.1. Solar photovoltaic (PV):

Solar photovoltaic (PV), refers to the technology of using solar cells to convert solar energy to electricity. The exploited potential is less than 150 MW, and of that only about 20 MW is grid-connected. In India the vision attempts to reach the installed capacity of 1~2 GW by 2013, 4~10 GW by 2017 and 20GW by 2022.

1.2. Concentrating solar power (CSP):

CSP systems use mirrors to concentrate sunrays and produce heat and steam to generate electricity by a conventional thermodynamic cycle. The exploited potential is very low or negligible. The National Solar Mission has already allocated 500 MW to Indian corporate and these CSP plants are currently being commissioned.

1.3. Solar thermal for heating purposes:

Solar thermal energy for heating and drying has significant potential in India. Studies have shown that energy from solar thermal used for industrial heating and drying can save up to 4.5 million tons of furnace oil or diesel per year. Specific industries that could find solar heating and drying applicable are food and beverages, transport, textiles and chemicals.

1.4. Solar water heating:

The total potential in India for solar water heating is about 140 million sq. meters. Of this, the total installed capacity is about 3.5 million sq. meters. Every year, over 20,000 solar water heaters are installed across India, according to some estimates. The Jawaharlal Nehru National Solar Mission targets to install 20 million square meters of solar water heating systems by 2022.

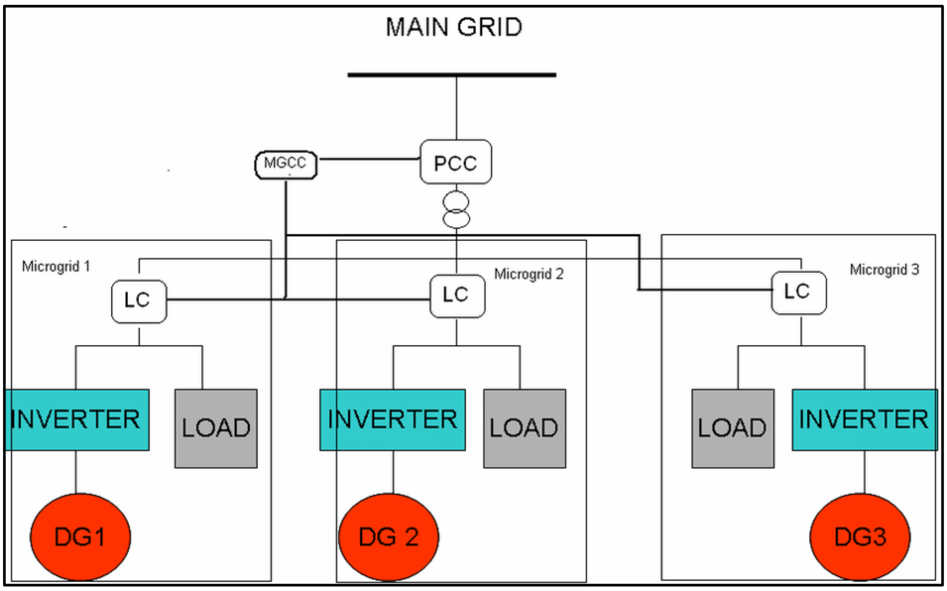

Figure. 1: Block diagram of Microgrid

2. Literature review:

(Dalla Vecchia et al., 2019) This paper introduces a new family of non-isolated dc-dc converters that are generated by the integration of the active switched-capacitor (ASCC) and the conventional commutation cell (CCC). Based on the commutation cell concept, the new conceived hybrid active commutation cell (HACC) provides three different types of hybrid converters: buck, boost and buck- boost. All three converters are investigated in this study through the following approaches: topological stages, static gain analysis considering the switched - capacitor features, generalization of the HACC and gain for Mcells and steady-state analysis. The buck version presents a high conversion rate, which demonstrates that it has potential for step-down applications. To verify the proposed topologies, a prototype was built with the following specifications: 600 V input voltage, 150 V output voltages, 70 kHz switching frequency and 1 kW rated power. Efficiency close to 95% was obtained at 1 kW for the buck topology, which demonstrates that the proposed HACC can provide gain and high efficiency at the same time.

(Dida, 2019) This paper proposes a variable speed control algorithm for a grid connected doubly- fed induction generator (DFIG) system. The main objective is to track the maximum power point by using an adaptive perturbation and observation (P&O) technique based on fuzzy logic controller (FLC), and compares it with the conventional optimal torque (OT) control method for large inertia wind turbines. The role of the FLC is to adapt the step-size of the P&O method according to the operating point. The control system has two control systems for the rotor side and the grid side converters (RSC, GSC). Active and reactive power control of the back-to-back converters has been achieved indirectly by controlling q-axis and d-axis current components. The main function of the RSC controllers is to track the maximum power through controlling the rotational speed of the wind turbine. The GSC controls the DC- link voltage, and guarantees unity power factor between the GSC and the grid regardless of the magnitude and direction of the slip power. The proposed system is developed and tested in MATLAB/ SimPowerSystem (SPS) environment.

(Ansari, 2019) Renewable energy is plentiful, and the technologies are improving all the time. There are many ways to use renewable energy. We have realized that our fossil and atomic fuels will not last forever, and that their use contributes to environmental pollution. Renewable energy - which basically comes from the sun in one way or another - provides opportunities for an unlimited, sustainable energy supply with low environmental impact. Most of the power generation in India is carried out by conventional energy sources, coal and mineral oil-based power plants which contribute heavily to greenhouse gases emission. This focuses the solution of the energy crisis on judicious utilization of abundant renewable energy resources. . It begins by describing the importance of renewable energy and its advantages over fossil fuels. This paper gives an overview about types of renewable energies and their effective uses. It also reviews the multi-criteria assessment of different renewable energy and draws out vital conclusions.

(Muhtadi et al., 2018) Due to sheer dependency upon fossil fuel sources, Bangladesh as a country is not free from numerous negative aspects. Country's requirement for a certain portion of power be generated from renewable energy sources is due and required renewable energy target (RET) needs to be fulfilled. In this study, potential of distinguished coastal sites for entirely renewable energy such as solar and wind sources based microgrid for chosen community is explored. Microgrid architecture is appropriate considering the coastal areas' geographical locations and due to the inconvenience in grid extension. Study suggests, potential of coastal sites are found to be feasible for such structures based on real case scenario data and modeled technical scheme.

(Muhtadi & Saleque, 2018) This paper presents modeling and simulation of an entirely renewable energy based microgrid in MATLAB/Simulink environment for a chosen sample number of population at St. Martin's Island in Bangladesh. The proposed microgrid system consists of Doubly- fed induction generator (DFIG) based wind turbine farm, solar PV array farm and AC loads. The wind turbine farm is interfaced to the microgrid along with PV farm while the PV array is connected via an inverter and a boost converter with a maximum power point tracking system. The microgrid system is tasked with meeting the peak load demand power and primary load demand power for the community, entirely from solar PV and wind farm, whereas in present the region is dependent on diesel generators for fulfilling electricity demand. The overall stability of the microgrid is maintained by employing a small portion of generation mean using redundant diesel generators to meet minimum power requirement of the community for a time being when it's acute and beyond favorable conditions to produce power from renewable energy sources. Finally, simulation study of the microgrid is carried out for various operating conditions and proposed microgrid's feasibility and functionality are observed as tasked earlier.

3. Problem formulation:

This paper presents a green energy solution to a microgrid for a location dependent on a diesel generator (DG) to meet its electricity requirement. This microgrid is powered by two renewable energy sources namely wind energy using doubly fed induction generator (DFIG) and solar photovoltaic (PV) array. The solar PV array is directly connected to common DC bus of back-back voltage source converters (VSCs), which are connected in the rotor side of DFIG. Moreover, a battery energy storage (BES) is connected at same DC bus through a bidirectional buck/boost DC-DC converter to provide path for excess stator power of DFIG. The extraction of maximum power from both wind and solar, is achieved through rotor side VSC control and bidirectional buck/boost DC- DC converter control, respectively. Moreover, the control of load side VSC is designed to optimize the fuel consumption of DG. A novel generalized concept is used to compute the reference DG power output for optimal fuel consumption. The microgrid is modelled and simulated using Sim Power Systems tool box of MATLAB, for various scenarios such as varying wind speeds, varying insolation, effect of load variation on a bidirectional converter and unbalanced nonlinear load connected at point of common coupling (PCC). The DFIG stator currents and DG currents are found balanced and sinusoidal. The model is further updated with DC-DC boost converter connected to PVA for maximum power extraction controlled by MPPT algorithm.

4. Proposed methodology:

Maximum power point tracking (MPPT) is a technique used with wind turbines and photovoltaic (PV) solar systems to maximize power output. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries. MPPT plays an important role in photovoltaic system because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Maximum power point is the voltage and current at which the PV module can produce maximum available power. The IPV- VPV characteristic is non-linear and varies with solar irradiation. Now, consider the power-voltage a characteristic of the PV panel. There is a unique point on the IPV- VPV or PV curve called the maximum power point (MPP) at which the entire PV system operates with maximum efficiency and produces its maximum output power. The location of MPP is not known, but it can be located either through calculation models or by search algorithms. There are many algorithms for implementing MPPT, among those Perturb and Observe method (P&O) & Incremental Conductance method (IC) are the most popular algorithms. The algorithm we use here is a modified version of incremental conductance method. In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module.

Among the MPPT algorithms implemented in TEG systems, perturb and observe (P&O) and open circuit voltage (OCV) methods are the most widely used. The P&O algorithm falls under the category of a hill climbing algorithm. Hill climbing algorithms are named so due to the algorithm taking steps over sampled data to reach a desired value, in the case of the P&O this takes steps towards the MPP by increasing or decreasing the duty cycle. A boost converter with variable output voltage and a new maximum power point tracking (MPPT) scheme is proposed which improves the efficiency by 10%. In this study, a modified P&O algorithm is proposed. Simulations and experiments are conducted to evaluate the tracking efficiency of the proposed system.

The most commonly used MPPT algorithm is P&O method. This algorithm uses simple feedback arrangement and little measured parameters. In this approach, the array voltage is periodically given a perturbation and the corresponding output power is compared with that at the previous perturbing cycle. The perturbation and observation method measures ΔP and ΔV to judge the momentary operating region and then according to the region, the reference voltage is increased or decreased such that the systems operates close to the maximum power point. As the method increases or decreases only the reference voltage, the implementation is simple. However, the method cannot readily track immediate and rapid changes in environmental conditions. The algorithm can be easily understood by the following flow chart:

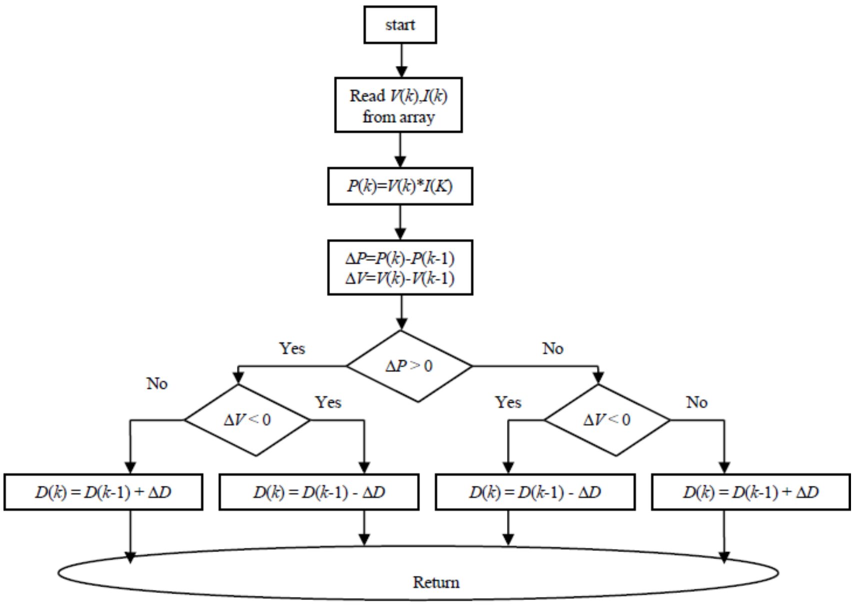

Figure. 2: Flow Chart of P&O Algorithm

5. Result & analysis:

The microgrid based on wind turbine driven DFIG, DG and solar PV array with BES, is simulated using MATLAB. Various signals used to analyze the system performance, are rms value of phase voltage (Vr), system frequency (fL), DFIG rotor speed (?r), DG power (PD), wind power from stator (Pw), solar PV power (Psol), load power (PL), LSC power (PLSC), DC link voltage (Vdc), battery current (Ib), battery voltage (Vb), wind speed (Vw), insolation (G), rotor power coefficient (Cp), a- phase stator current (isa), rotor currents (irabc), a-phase DG current (ida), a-phase PCC voltage (vLa), stator currents (isabc), DG currents (idabc), load currents (iLa, iLb and iLc), neutral current (iLn) and LSC currents (icabc). The parameters used for the simulation are mentioned in table.

6. Simulation parameters:

Table. 1: Simulation Parameters

Parameter	***Value***
Doubly Fed induction generator (DFIG)	1.5 MW
Line voltage	415 V
Frequency	50Hz
Stator (Rs and Ls)	0.023 0.18
Rotor (Rs and Ls)	0.016 0.16
Magnetizing inductance Lm	2.9
PV Irradiation	1000 W/m^2
Temperature	30^0 C
Duty Cycle	0.5
Battery Parameter	Nominal voltage (V) 500, Rated capacity (Ah)=200 Ah
Proportional Integral Kp and Ki	0.2 and 0.0023
PWM Switching frequency (Hz)	5000

The proposed system with DFIG connection to grid is shown in the figure given below.

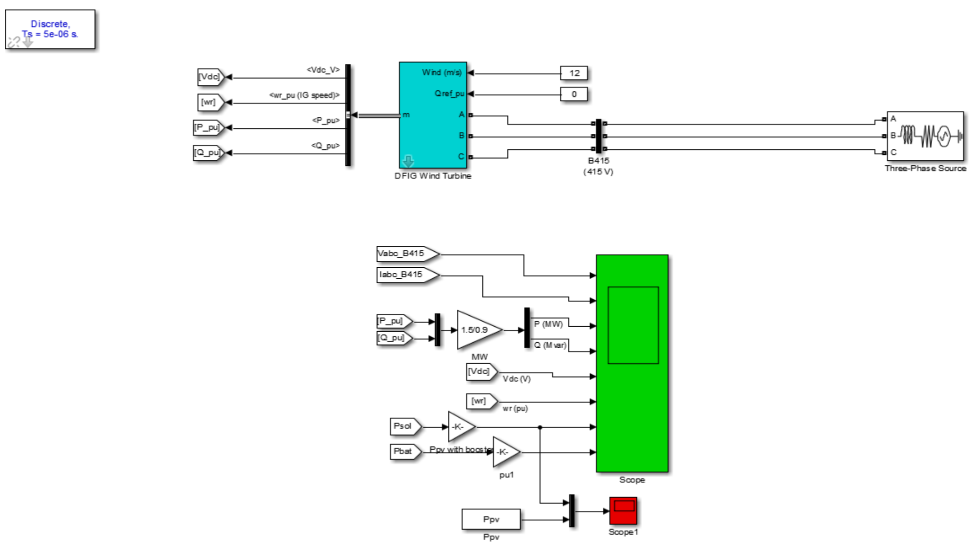

Figure. 3: Proposed system with DFIG connection to the grid

7. Conclusion and future scope:

The microgrid based on wind turbine driven DFIG, DG and solar PV array with BES, with minimum number of converters, has been presented. The solar PV array is directly connected to DC link of back-back connected VSCs, whereas BES is connected through a bidirectional buck/boost DC-DC converter. The system has been simulated for various scenarios such as variable wind speeds, variable insolation and unbalanced nonlinear load connected at PCC. Moreover, the performance of bidirectional buck/boost DC-DC converter at change in the load has been investigated. Simulated results have shown the satisfactory performance of the system to achieve optimal fuel consumption. The DFIG stator voltages, currents and DG currents, are found balanced and sinusoidal, as per the IEEE 519 standard. There is a performance enhancement in the PVA module with more power injection to the battery from 0.3MW to 0.5MW as the PVA module is updated with DC-DC booster converter controlled by P&O MPPT technique.

8. Future scope:

The complete system can be updated with more renewable sources which can be connected at the DC link like fuel cell, transducers, bio gas plants which can inject more power to the grid or store more power into the battery storage system. The controller on line side converter can be updated with adaptive controller improving the settling time of the power generation and reduce ripple in DC link voltage.

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