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HYBRID ENERGY MANAGEMENT-BASED INTELLIGENT NON-INTEGER CONTROL FOR SMART DC-MICROGRID OF SMART UNIVERSITY

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Abstract— Global environmental changes, nuclear power risks, losses in the electricity grid, and rising energy costs are increasing the desire to rely on more renewable energy for electricity generation. Recently, most people prefer to live and work in smart places like smart cities and smart universities which integrating smart grid systems. The large part of these smart grid systems is based on hybrid energy sources which make the energy management a challenging task. Thus, the design of an intelligent energy management controller is required. The present paper proposes an intelligent energy management controller based on combined fuzzy logic and fractional-order proportional-integral-derivative (FO-PID) controller methods for a smart DC-microgrid. The hybrid energy sources integrated into the DC-microgrid are constituted by a battery bank, wind energy, and photovoltaic (PV) energy source. The source-side converters (SSCs) are controller by the new intelligent fractional order PID strategy to extract the maximum power from the renewable energy sources (wind and PV) and improve the power quality supplied to the DC-microgrid. To make the microgrid as cost-effective, the (wind and PV) energy sources are prioritized. The proposed controller ensures smooth output power and service continuity. Simulation results of the proposed control schema under Matlab/Simulink are presented and compared with the super twisting fractional-order controller.

Key words: *Renewable energy, smart university, DC-microgrid, energy management control, fuzzy logic control, fractional order control.*

I. INTRODUCTION

Traditional electric power system can be broadly divided into three main categories: electricity generation, transmission, and distribution systems. The generating stations are connected to the distribution system through transmission lines and the distribution system supplies electricity to all loads in a particular region. For a number of reasons, mainly technical and economical, individual power systems are connected together to form power pools. These regional or area electric grids operate independently, but are also interconnected to form a utility grid. Nowadays, electric power systems are evolving to more complex and interacting sets of systems at multiple levels by means of the development of new technologies, along with innovations in business models and policies. In this way, the whole system tends to be a conglomerate of smarter grids that interconnect hardware, software and communication technologies.

The European Technology Platform Smart Grids defined a smart grid (SG) as “an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies”. In SG, information and communication technology (ICT) enhanced appliances can adjust their electricity demand according to grid conditions and local energy generation. Currently, grid operators can already have agreements with industries on electricity demand for economic use of the electricity grid, but ICT technologies can enable a diverse set of household appliances to automatically shift their demand. For example, a smart washing machine can start its cycle when PV solar panels are producing energy, stops operating when production is low because of a passing cloud, and continue its operation again when the sky is clear again. However, all of the electrical appliances are not suitable for shifting their demands subject to grid conditions, for example, the electricity demands of appliances such as lightning and television can largely be considered as non-shiftable demands. Hence, demand response (DR) can also reduce the impact of clean energy technologies on the demand side, by alleviating peaks in electricity demand of technologies such as heat pumps and electric vehicles (EVs). Accordingly, distributed solutions are becoming an integral part of the modern electric power system, providing improvements in energy efficiency, generation, and demand-side flexibility, as well as integrating diverse distributed energy resources (DERs) such as renewable energy sources (RES), energy storage systems (ESS), electric vehicles, smart devices and appliances, among others. In this context, distributed autonomous systems known as microgrids (MGs) have appeared as a natural component of the SG to provide controllability and management to local power areas and enhance the power system with resiliency properties.

II. RELATED WORK

H. T. Dinh, J. Yun, D. M. Kim, K. Lee, and D. Kim [1], With the development of new technologies in the field of renewable energy and batteries, increasing number of houses have been equipped with renewable energy sources (RES) and energy storage systems (ESS) to reduce home energy cost. These houses usually have home energy management systems (HEMS) to control and schedule every electrical device. Various studies have been conducted on HEMS and optimization algorithms for energy cost and peak-to-average ratio (PAR) reduction. However, none of papers give a sufficient study on the utilization of main grid's electricity and selling electricity. In this paper, firstly, we propose a new HEMS architecture with RES and ESS where we take utilization of the electricity of the main grid and electricity selling into account. With the proposed HEMS, we build general mathematical formulas for energy cost and PAR during a day. We then optimize these formulas using both the particle swarm optimization (PSO) and the binary particle swarm optimization (BPSO). Results clearly show that, with our HEMS system, RES and ESS can help to drop home energy cost significantly to 19.7%, compared with the results of previous works. By increasing charge/discharge rate of ESS, energy cost can be decreased by 4.3% for 0.6 kW and 8.5% for 0.9 kW.

C. Byers and A. Botterud [2], Current capacity markets often consider capacity credits from each resource independently, irrespective of the portfolio of resources, potentially overvaluing or undervaluing the capacity contribution of variable renewable energy (VRE) and energy storage (ES) in the grid. We propose a method for calculating the standalone and integrated capacity value of an added VRE resource with existing ES resources. The difference between the integrated and standalone value is the portfolio effect. This is the additional capacity value gained by the synergy of VRE and the existing fleet.

M. Rizwan, L. Hong, W. Muhammad, S. W. Azeem, and Y. Li [3], Renewable energy sources powered distributed generation (RES-DG) is getting more indispensable to encounter the considerable increase in demand for electric energy owing to its techno-economic benefits and eco-friendly nature. An economic solution to this demand can only be obtained with the optimal placement and sizing of RES-DGs. The optimal siting and sizing of RES-DG, such as Photovoltaic (PV) and Wind Turbine (WT) is still a hot topic due to the uncertainties in solar irradiance (SI) and wind speed (WS). The main objective of this research paper is to develop a RES-DG siting and sizing strategy for the discrete, nonlinear siting and sizing pattern of RES-DGs using a novel hybrid Harris' Hawk optimizer (HHHO), considering the stochastic nature of SI and WS. The Weibull and Beta probability density functions (PDFs) are utilized for modeling the stochastic nature of WS and SI, respectively. The optimization of the multi objective function comprises active power loss reduction, enhancement in voltage profile, and improvement in voltage stability index (VSI). Different scenarios of single and multiple RES-DGs and capacitor banks (CB) are examined to validate the efficiency of the proposed novel HHHO based RES-DGs siting and sizing strategy. The results show a considerable reduction in power loss, enhancement in the system voltage profile, and improvement in VSI. Evaluation of results by comparing with state-of-art hybrid algorithms shows that the proposed solution using HHHO algorithm is globally optimum.

III. SYSTEM MODELING

A new fractional order PID controller is proposed combined with a fuzzy logic method to address the problems faced by the conventional integer controls in hybrid energy management. Fractional-order controllers offer additional advantages over integer order controls such as robust behavior to oscillations and the measurement noise and high degree of freedom. The proposed new controller is integrated With an energy management unit for a DC-microgrid integrated with several stochastic sources and essential DC loads illustrated by Figure 4.1. The proposed intelligent Fractional-Order PID (IFO-PID) controls will be used as a low-level controller, when the energy management unit serves as high-level controller which generates appropriate references for the IFO-PID and monitors the generated and consumed power. The novelty and contribution of the present work are summarized as follows, the new fractional order PID (FO-PID) controller combined with a fuzzy logic strategy is developed for a DC-microgrid integrated with several stochastic sources and essential DC loads. The fuzzy logic method is selected as a fuzzy gain supervisor to adaptively adjust gains of the FO-PID which greatly enhances the robustness of the proposed approach against various uncertainties external disturbances. The essential characteristic of this approach is the extremely reduced number of the fixed gains used by the proposed strategy which avoids its sensitivity to parameter uncertainties, which highly improves the robustness property and global stability of the system. The global stability of the system and is ensured and further validated by extensive simulation results.

a) Mathematical Description of The Hybrid Energy System

The studied hybrid energy system integrated smart DC-microgrid is illustrated by below figure where three main parts can be distinguished: the hybrid energy sources constituted by the wind energy, solar energy, and the battery storage systems connected to the DC-link through their respective converters.

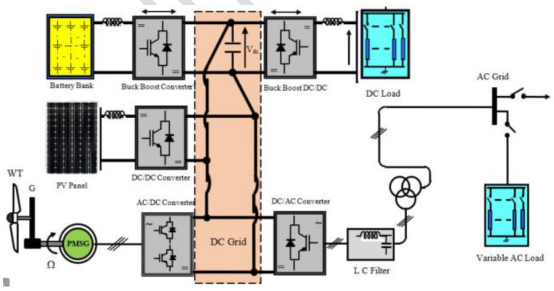

Figure-1: Studied hybrid system structure.

The second part represents the loads assumed to be a priority which in the case of a smart university may include laboratory experimentation benches, fans, and lighting. Amaximum power point tracking algorithm is used on both the wind and solar (PV) conversion systems to force them to operate at maximum power. The energy management unit computes the total consumed and produced energy to select the adequate control modes.

b) Wind System Model

The mathematical model of the wind power that can be transformed by the turbine is given by:

$$P_m = \frac{1}{2}\rho C_p(\beta,\lambda)Av^3$$

$$T_m = \frac{P_m}{\omega_t}$$

$$C_p(\beta,\lambda) = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\left(\frac{21}{\lambda_i}\right)}$$

$$\lambda_i^{-1} = (\lambda + 0.08\beta)^{-1} - 0.035\left(1+\beta^3\right)^{-1}$$

$$\lambda = \frac{\omega_t R}{v},$$

Depending on the state of the storage system, which it will be discussed in the energy management section, the wind system can be operated under MPPT for maximum power extraction or off-MPPT for power balance as shown in Fig. 2. The MPPT algorithm is detailed in the flowchart of Fig.3.

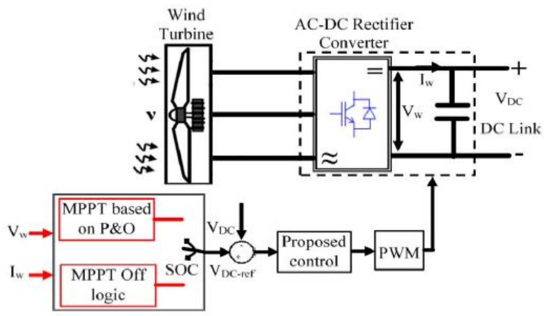

Figure-2: Wind energy system with controller.

In case of power generation excess and no storage capacity in the battery system, the proposed energy management unit (EMU) switches the wind controller from the MPPT mode to the off-MPPT mode in order to reduce the generated power and maintain a balanced power in the standalone system. In off-MPPT, the voltage reference is carried out as:

$$V_{ref} = \frac{P_L - P_w}{I_w}$$

Where, PL is the load power and Pw is the power from the wind energy system.

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c) Solar Power System Model

The solar conversion system (SCS) is constituted by the PV panel connected to the DC-link through a DC-DC boost converter. The SCS mathematical model is given as below,

$$\frac{dV_{pv}}{dt} = \frac{I_{pv}}{C_{pv}} - \frac{I_{Lpv}}{C_{pv}}$$

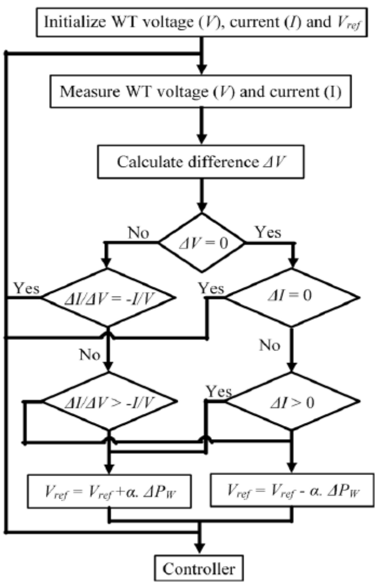

Figure-3: MPPT algorithm of the wind system.

d) Battery System Model

In this application, a standard battery is connected to the DC-link through a bidirectional DC-DC back-boost converter connected at the DC-link of the microgrid (see Figure 4). The role of this converter is to maintain the DC-link voltage constant despite the power changes in the sources and the load. The DC-link voltage is regulated at it references to compute the reference current of the battery and then design the voltage controller through the proposed strategy as shown in Fig. 4.6. The Battery State of Charge (SOC) model is modeled as described below:

$$SOC = 100\left(1 + \frac{\int I_{bat}dt}{Q}\right)$$

The SOC, the amount of electricity stored during the charge, is an important parameter to be controlled. The battery SOC must detect by the proposed supervisory system to make decisions according to its status and the required power. In a battery, the ampere-hours stored during a time t corresponds to a nominal capacity Q and a charging current *Ibat*. The battery charge-discharge depends on the available power, the demand and the SOC.

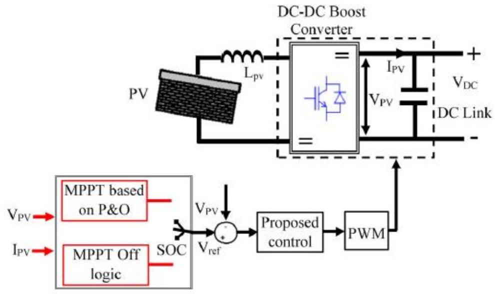

Figure-4: Solar energy system with controller.

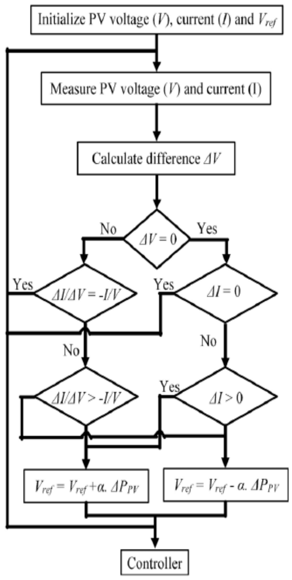

Figure-5: MPPT algorithm of the solar energy system.

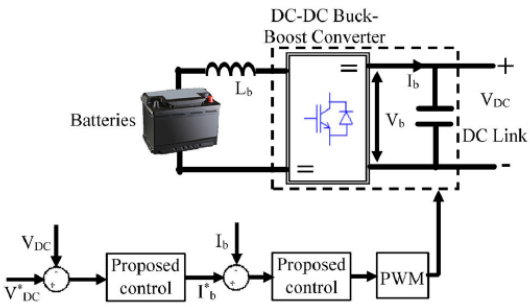

Figure-6: Battery storage system with controller.

e) Ac Grid Model

Similar wind and AC grid converters are used which is a buck-to- buck converter (see Figure 7). Then, the mathematical modeling of the AC grid converter system can be expressed as given below,

Vol 13, Issue 05, MAY/2022

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$$\frac{dV_g}{dt} = \frac{I_g}{C_g} - \frac{I_{Lg}}{C_g}$$

$$\frac{V_g}{L_g} = \frac{dI_g}{dt} + (1 - U_4)\frac{V_{dc}}{L_g} - D_7$$

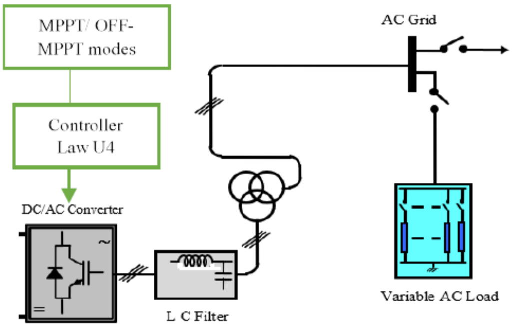

Figure-7: AC load system.

IV. RESULTS

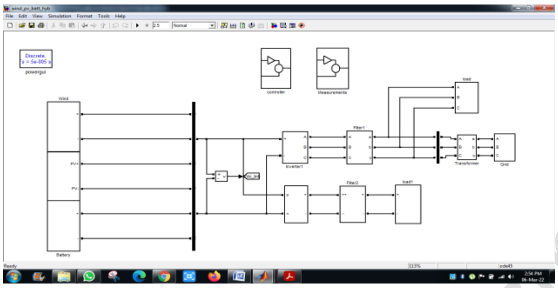

Figure-8: step changes

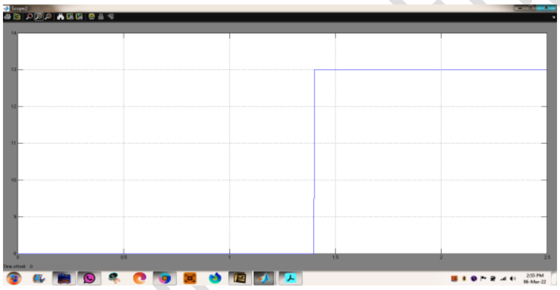

Figure-9: Wind Speed

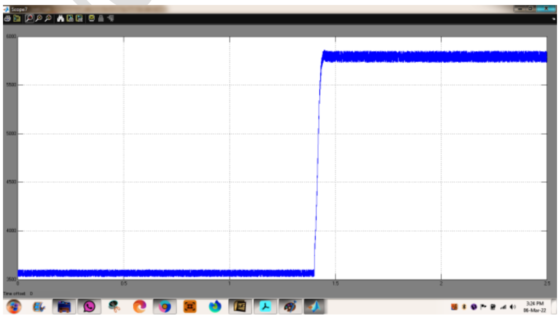

Figure-10: Wind Power

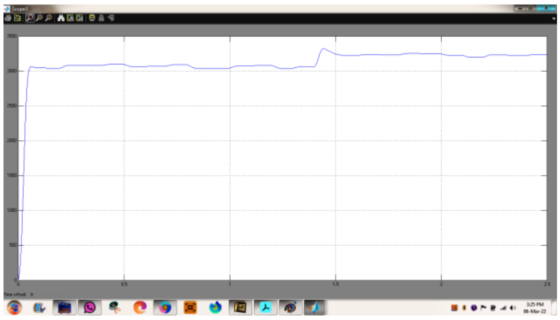

Figure-11: Solar Power

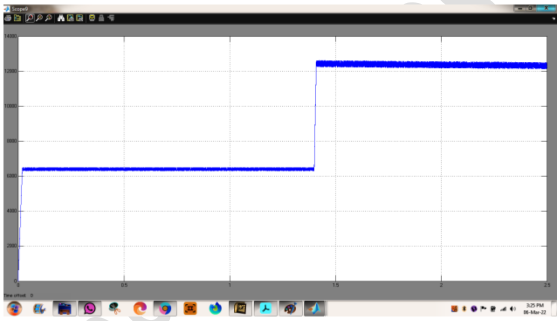

Figure-12: SSCs power

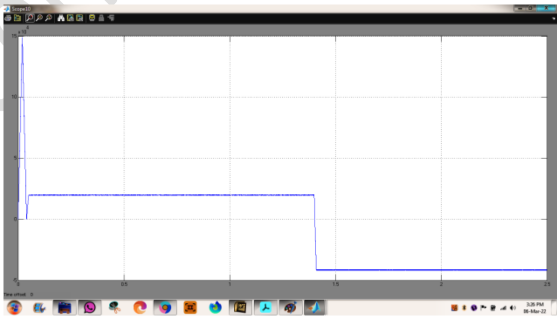

Figure-13: BSS power

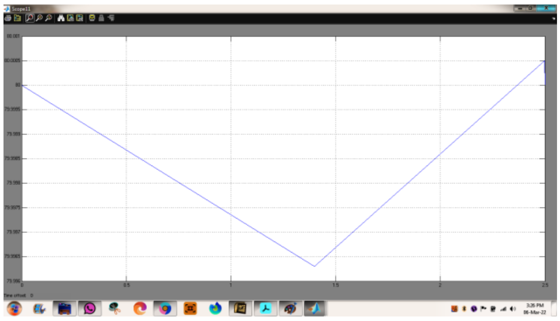

Figure-14: battery SOC

JES Journal of Engineering Sciences

Vol 13, Issue 05, MAY/2022

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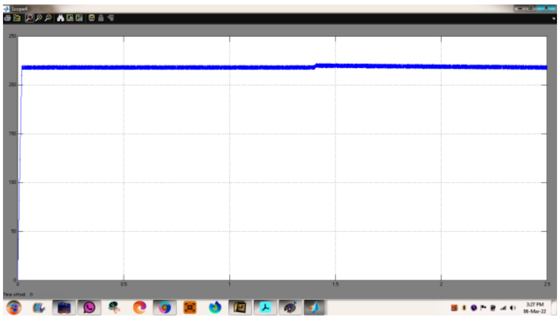

Figure-15: DC link voltage

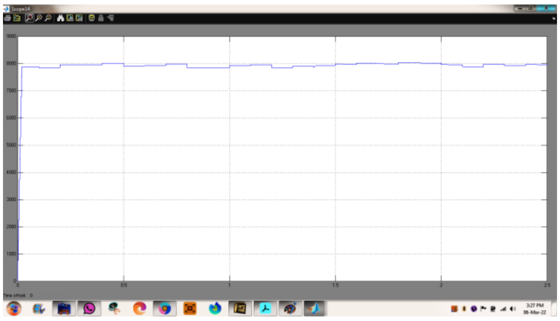

Figure-16: Load power

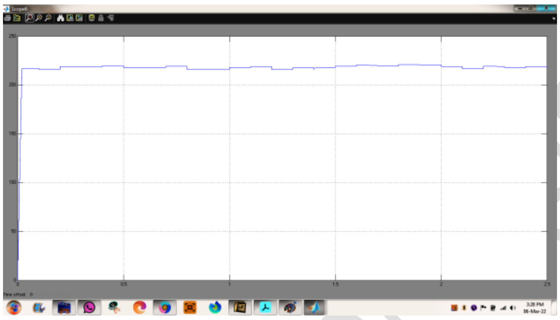

Figure-17: Load Voltage

VI. CONCLUSION

In this project, a novel intelligent fractional order PID controller is proposed for the Energy management of hybrid energy sources contacted to a smart grid through a DC-link voltage. The hybrid energy sources integrated to the DC-microgrid are constituted by a battery bank, wind energy, and photovoltaic (PV) energy source. The source side converters (SCCs) are controller by the new intelligent fractional order PID strategy to extract the maximum power from the renewable energy sources (wind and PV) and improve the power quality supplied to the DC-microgrid. To make the microgrid as cost-effective, the (Wind and PV) energy sources are prioritized. The proposed controller ensures smooth output power and service continuity. Simulation results of the proposed control schema under Matlab/Simulink are presented and compared with the other nonlinear controls.

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