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Compensation of Energy Demand During Peak Period Using Gas Turbine in Smart Grids

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ABSTRACT: Smart grids have been proposed as a way to increase grid robustness and reduce consumption peaks and in the mean time decrease electricity costs for the end users. This paper aims to develop generic models for smart grids focusing on gas turbine response which is used to baying, if it is possible, to increase consumption energy, decrease electricity cost and at the same time increase grid stability. Models have been developed by using Modelica language. Based on simulations of the models, it is concluded that the consumption peaks in the grid can be increased while is the mean time grid robustness in terms of withstanding short power outages is improved. Furthermore this effort could reduce electricity cost for the end users as well.

KEYWORDS: Smart grid, Modelica, Efficient Communication, System Security, Peak Period, Synchronization.

I.INTRODUCTION

Today most electricity is produced mainly with fossil fuels, nuclear and hydro. These energy sources are dispatchable in their nature, i.e. the amount of electricity that is produced is determined exactly and can be increased or decreased within a specific time frame according to changes in demand. Due to the probable negative impact of CO2 [1] on the environment and the depletion of fossil fuels it is essential that the electrical energy consumption has to decrease and that the consumption is done in a more efficient way. Smart grids is a concept that tries to solve these issues. The concept is not well defined but it circles around communication between different actors such as power producers, transmission system operators, distribution system operators, and end users. The communication might contain minute wise information about current production, consumption and price of electricity. In the short term, this may be used to create incentives to lower consumption of electricity at peaks of high demand. In the longer run, households may have automatic systems that will close down low priority loads, e.g. outdoor lights, during hours of high demand (high price) and start resources with low priority, e.g. laundry machine or dishwasher, during hours of low demand. Small-scale power generation or micro generation, such as solar and wind power at household level, might be a cost efficient way of generating electricity locally, both to fulfil the consumers' needs but also in order to sell to the electric grid.
Smart grid as an automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid, the benefits of distributed computing, communications to deliver real-time information, to enable the near-instantaneous balance of supply and demand at the device level [2] .They continue with: "While supply and demand is a bedrock concept in virtually all other industries,it is one with which the current grid struggles mightily because, as noted, electricity must be consumed the moment it is generated. Without being able to ascertain demand precisely, at a given time, having the ‘right’ supply available to deal with every contingency is problematic at best. This is particularly true during episodes of peak demand, those times of greatest needfor electricity during a particular period.

II.SMART GRID INTEGRATED SYSTEM MODEL

Although there are multiple modelling tools available for micro-grid design, simulation, and optimization, the platform selected to model the micro-grid test and training facility was the Micro grid Modelica library developed by Model on, along with a commercial modelling and simulation platform that uses the Optimise Compiler Toolkit for model simulation and optimization (Windahl, 2019).This platform was selected based on its flexible, multi-physics, and

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highly customizable modeling and optimization framework, its ability to accommodate models of varying levels of fidelity, its ability to provide physical (rather than only mathematical) representation of micro-grid components, and its ability to support causal analysis. A review of this and other modeling and optimization tools. Using the Microgrid Modelica library component models, an integrated system model fig 1, was assembled, including a gas turbine generator, a battery, a simple PV system, a simplified representation of a grid connection, conversion components, and a variable load.

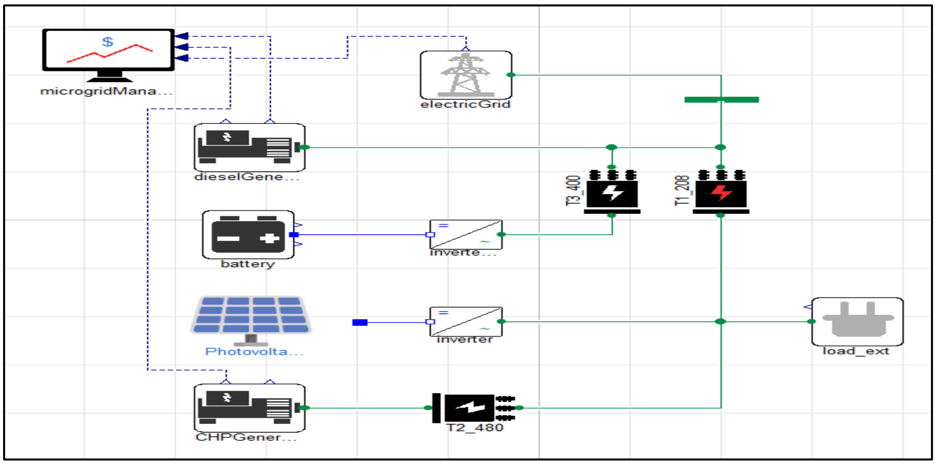

Fig.1:Micro-Grid Integrated System Model.

- ***Photovoltaic Cell Mode***

The Microgrid library includes a PV model that can be configured to represent both flat panel PV and CPV systems using panel surface area, solar irradiance, temperature, system capacity and efficiency. However, for the purposes of this study, a simple PV model was used. Note that PV output was limited to 176 kW to leave room for the 40 kW CHP power generator. PV Watts data is based on multi-year weather data averages as shown in the fig 2 Modelica diagram and gives at the end only the needed points to connect the PV cell with the outer world like amount of solar radiation intensity, thermal heat exchange through the heat port and other electrical systems through the positive and negative pins. The configuration used for testing the Cell 2 lines module is shown in fig 3.

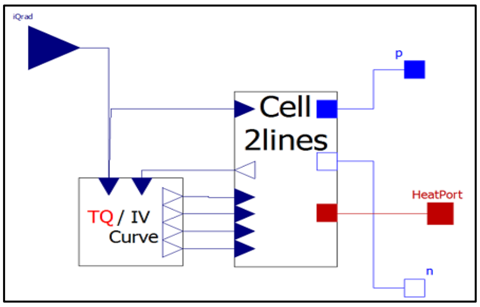

Fig.2: Cell 2 lines Modelica diagram

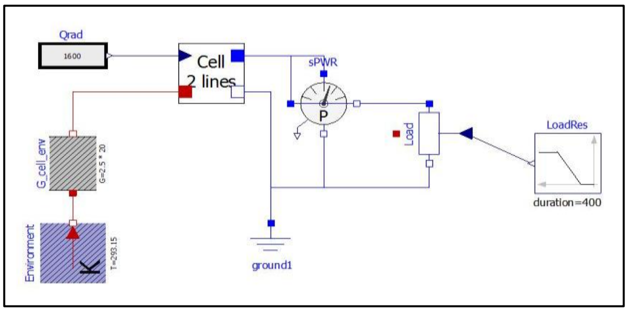

Fig.3: cell 2 lines test configuration

- ***Battery Model***

The internal construction of the battery is divided into two main parts; the electrical and thermal parts. First the electrical part consists of the positive and negative pins, simulated with a controlled voltage source in series with a small resistance, and is interfaced with a USB device, simulated with a resistive load. While the thermal part is composed of the heat port which is also connected to the heat ports of both resistances of the model R_b and R_L to indicate the amount of heat generated inside the model due to chemical reactions and represent the battery temperature to be connected through a thermal conductor to the temperature of the environment at the end which is expressed be the Cplate to simulate the heat transfer exchange effect.And more details about the battery model are shown in the fig 4.

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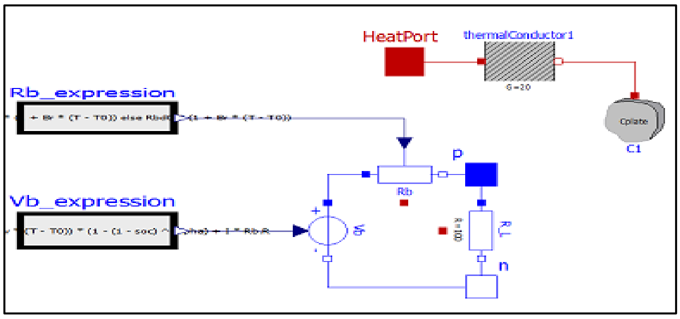

Fig .4: Battery Modelica diagram

- ***Inverter Model***

The model is done in a simple way to express the relation between input DC power and output AC power including the efficiency of the inverter.

$$Pac = Pdc \times \eta (1)$$

Then the Power on each side was declared in details, in the DC side power is a relationship of the variable DC current and voltages.

$$Pdc = Vdc \times Idc \qquad (2)$$

While at AC side the power is a function of imaginary and real voltages and currents defined in the phase's pins as described through the equations:

$$Pac = Vre \times Ire + Vim \times Iim \qquad (3)$$

Where, Vre is the real voltage, Ire is the imaginary voltage, Vim is the imaginary voltage, I_{im} is the imaginary current. Then the relation between control inputs to form the AC output voltage is described through the equations:

$$Vre = Vac \times cos\delta + (R + 2\pi fL) \times \sqrt{Ire^2 + Iim^2} \times Cos\left(\arctan\left(\frac{X}{R}\right) + \frac{\pi}{2}\right) \qquad (4)$$

$$Vim = Vac \times Sin\delta + (R + 2\pi fL) \times \sqrt{Ire^2 + Iim^2} \times sin\left(\arctan\left(\frac{X}{R}\right) + \frac{\pi}{2}\right) \qquad (5)$$

- ***The GT Models package***

The gas turbine package has the models that result from combining the basic parameterized gas turbine arrangement with given boundary conditions, sensors and actuators. The only model included to date is the complete Thermo Power Single Shaft Gas Turbine The Power SSGT model, as shown in fig 5. Due to unavailability of data, a still simple but complete model of the fuel inlet valve that takes valve position as input instead of fuel mass flow as a reference was added. This change was needed to harmonize the physical model of the turbine with the simplified power system GGOV1-based turbine model.

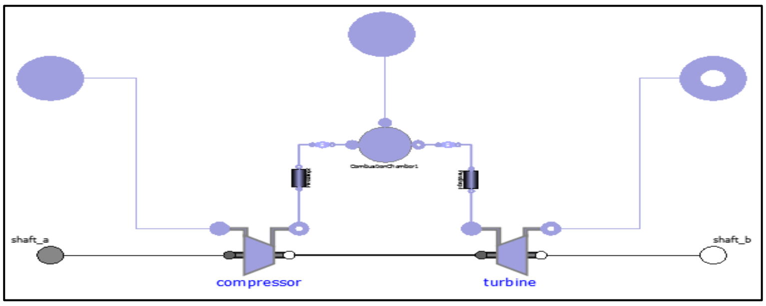

Fig. 5: The Single Shaft Gas Turbine model

- ***Controller***

All power systems must include a control strategy that describes the interactions between its components. The use of battery as a storage form implies thus the presence of a charge controller.The charge controller is used to manage the

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energy flow to PV system, batteries and loads by collecting information on the battery voltage and knowing the maximum and minimum values acceptable for the battery voltage. There are two main operating modes for the controller:

1) Normal operating condition, when the battery voltage fluctuates between maximum and minimum voltages.
2) Overcharge or over-discharge condition, which occur when the battery voltage reaches some critical values.

Iverter1ph Current Controller as shown in fig 6(a) provides current control in the synchronous reference frame for a 1-phase inverter. This is achieved by calculating the dq coordinates of the output current, using a PI controller for each coordinate. With this setup, the d coordinate can be used to control the active power and the q coordinate to control the reactive power. The output of this block is the duty cycle, which can then drive an inverter. PV control Inverter1phCompleteController as shown in fig 6(b) build upon the previous by adding an outer voltage control loop to the active power control (id), using an MPPT Controller block. It also adds a PLL block for synchronization with the grid. Fig 7, shows Control and communication systems include full control of the turbine, power inverter and start-up electronics as well as instrumentation, signal conditioning, data logging, diagnostics, and user control communications.

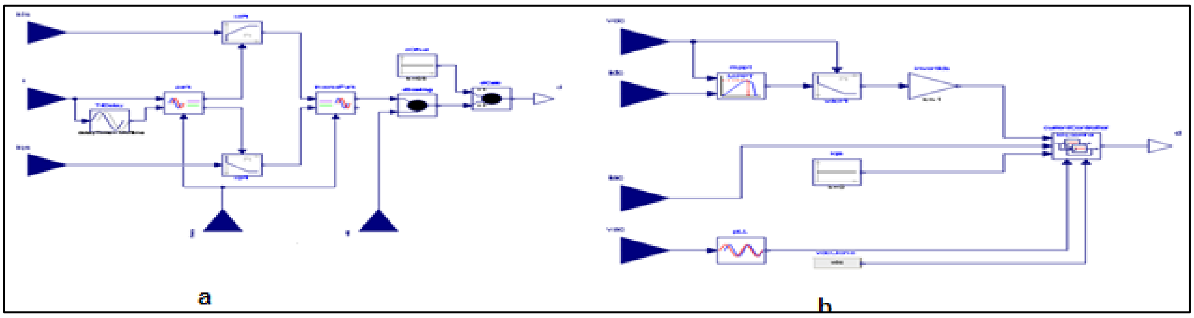

Fig .6:Inverter controllers in Control Assemblies

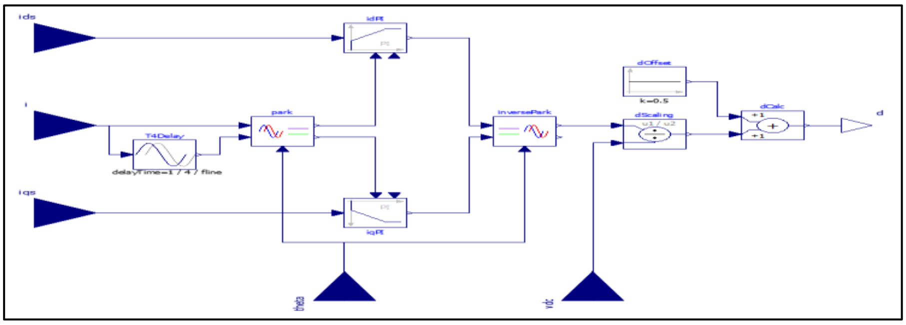

Fig .7: Control System Model

Speed control is usually modelled by using a lead-lag transfer function or by a PID controller [16][17].Lead-lag transfer function has been used in this work to represent the speed controller. The governor controls are with parameters gain, X, Y, and Z which can be adjusted so that the governor can act with droop or as isochronous governor. Acceleration control is primarily used for during turbine start-up to limit the rate of rotor acceleration prior to reaching operating speed.

- *Grid synchronization*

The inverter output current that is injected into the utility network must be synchronized with the grid voltage. The objective of the synchronization algorithm is to extract the phase angle of the grid voltage. The feedback variables can be converted into a suitable reference frame using the extracted grid angle. Hence, the detection of the grid angle plays an essential role in the control of the grid-connected inverter. The synchronization algorithms should respond quickly to changes in the utility grid. Moreover, they should have the ability to reject noise and the higher order harmonics. Many synchronization algorithms have been proposed to extract the phase angle of the grid voltage such as zero crossing detection, and phase-locked loop (PLL).The simplest synchronization algorithm is the zero crossing detection. However, this method has many disadvantages such as low dynamics. In addition, it is affected by noise and higher order harmonics in the utility grid. Therefore, this method is unsuitable for applications that require consistently accurate phase angle detection. Nowadays, the most common synchronization algorithm for extracting the phase angle

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of the grid voltages is the PLL. The PLL can successfully detect the phase angle of the grid voltage even in the presence of noise or higher order harmonics in the grid.

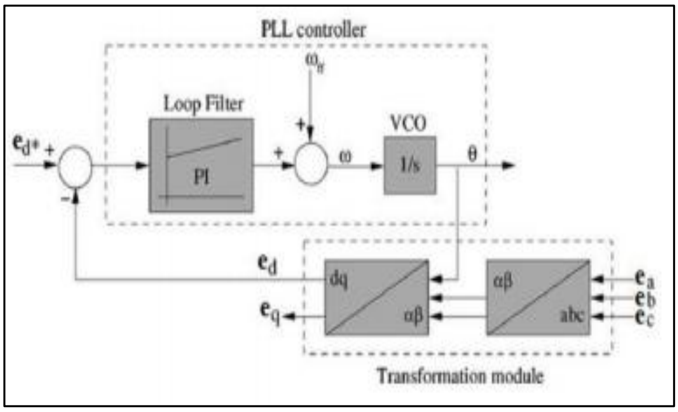


Fig .8: Basic structure of a PLL system for grid synchronization

As shown in fig 8, the PLL is implemented in the synchronous (dq) reference frame. The eabc is the sensed grid voltage which is then transformed into DC components using park transformation abc-dq. The PLL is locked by setting e*d to zero, which acts as a phase detector. A controller, usually PI, is used to control this variable, which brings the phase error to zero and acts as a loop filter. The ωff represents the utility nominal frequency that is added to the output of the regulator then outputted as the grid frequency. After the loop filter, whose output is the grid frequency, a voltage-controlled oscillator (VCO) is applied.

III. RESULT AND DISCUSSION

A simulation was performed on the grid model in Modelica environment which carried out on as shown in fig 9.

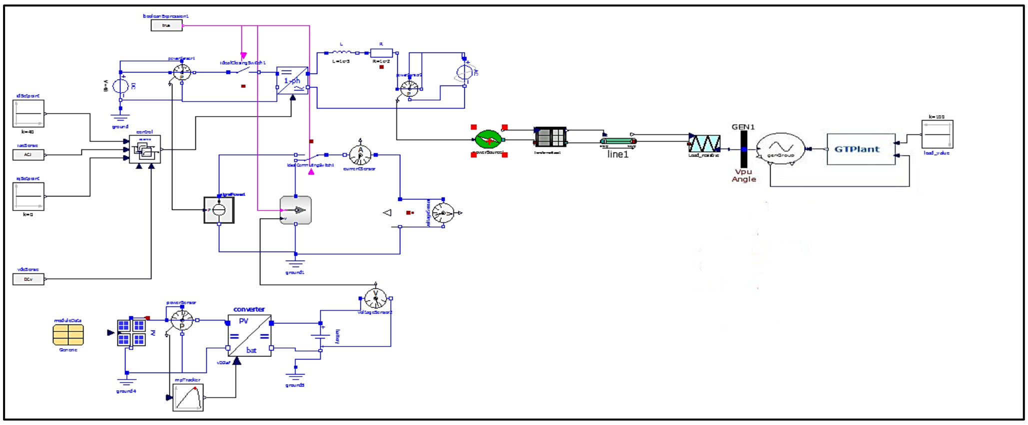


Fig .9: The grid model in Modelica

Fig 10(a) displays the variation of the DC voltage imposed by the inverter, controlled by the MPPT and current controller loop. The steps in voltage correspond to the adjustments that the MPPT controller follows the P&O algorithm. These steps are translated into the power steps shown in fig 10 (b). Eventually, since the irradiance and ambient temperature conditions are not changing, the controller finds the MPP. This is close to the 200W of the default PV Array parameter values.

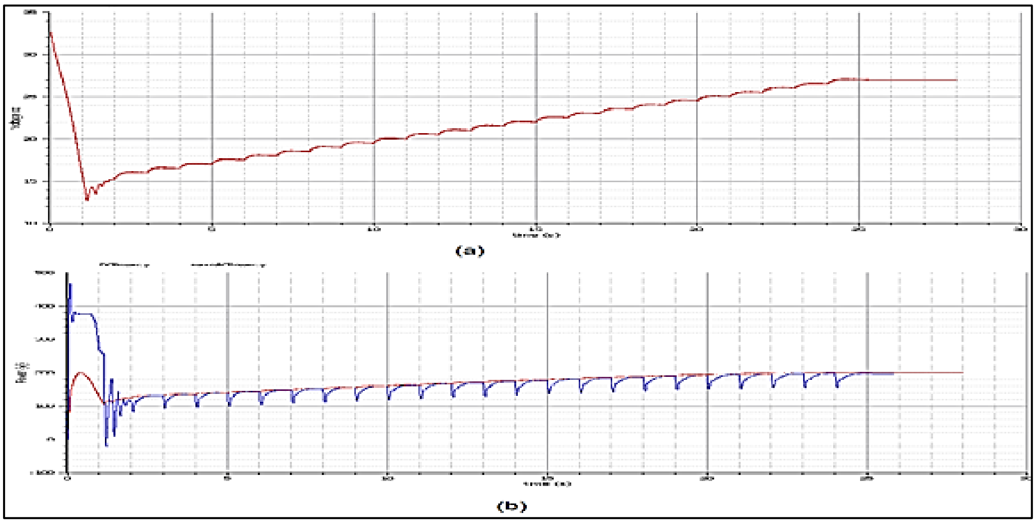
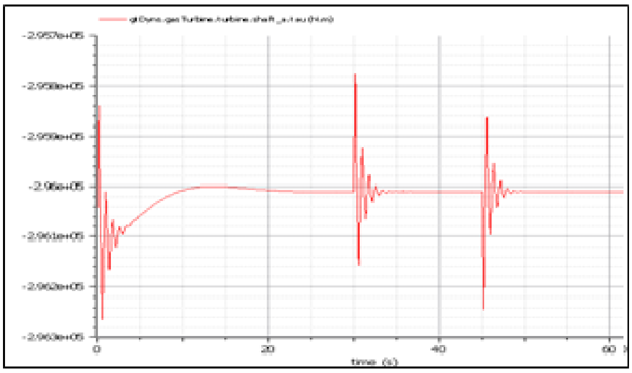


Fig.10: PVnverter1phSynch simulation results: (a) PV array voltage, (b) input and output power

The active power of the load was increased by 0.3 pu after 30 seconds of simulation .Fig 11,illustrates the mechanical output power of the GT to the input of the generator. It has been observed that mechanical output power of the GT takes a time of 5-10seconds to reach the input power demand. The electrical power output of the generator is shown in fig 12 and it has been found that it follows the power demand as desired.



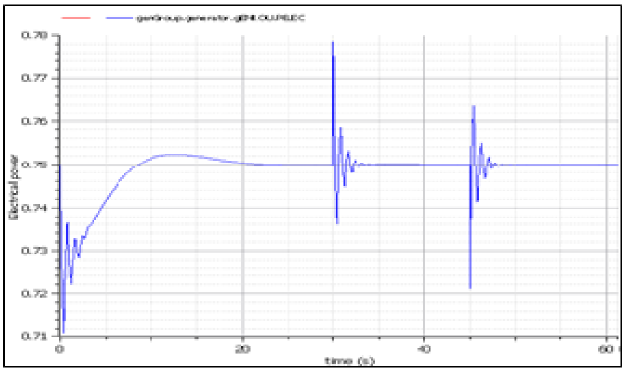
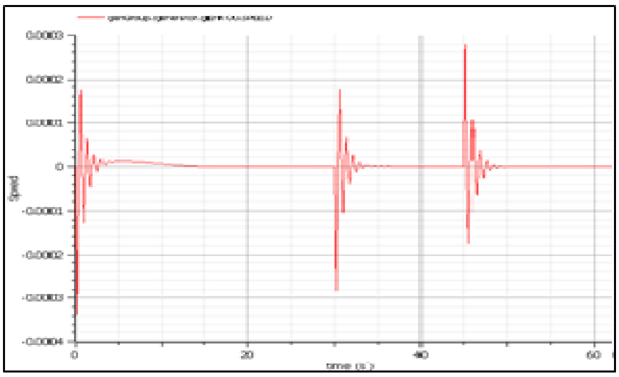


Fig .11: Mechanical power output of GT

Fig.12:Generator electrical power output

Speed control has been incorporated with the GT-generator system to maintain the speed constant, The GT-generator speed is represented in fig 13, which shows that the speed drops at the instant the load demand increases and maintained at that level as desired at steady-state.



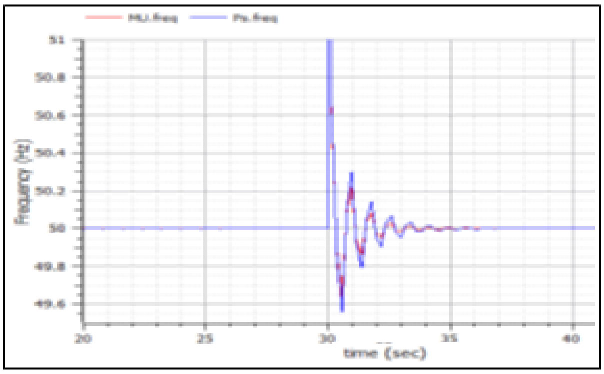


Fig. 13: The turbine speed deviation from nominal

Fig .14:The system frequency response

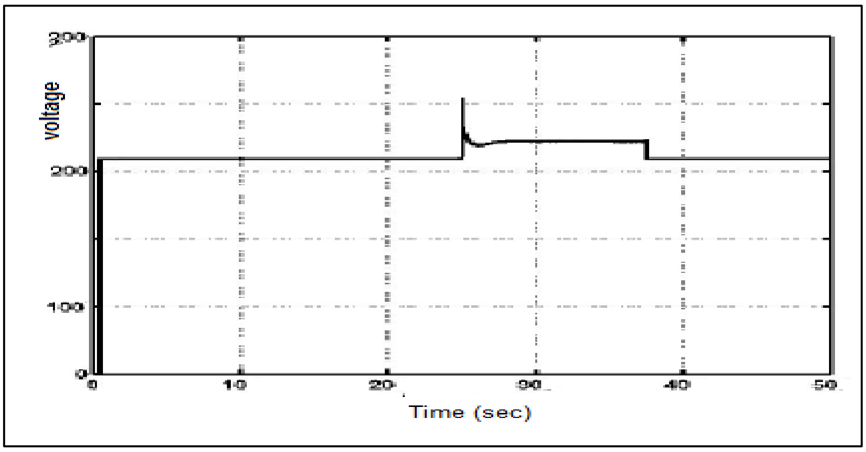


Fig .15: Total grid voltage

In this simulation, where the photovoltaic cells and a gas turbine generator work together within a smart grid, here the operation of the gas turbine generator is during the overload period, where the response of the gas turbine is fast to keep the network frequency at a constant value, as shown in fig14, as Shown in fig15 is the total network supply from both photovoltaic and gas turbine.

VI.CONCLUSION

The introduction of renewable energy sources into small grid applications offers the potential to reduce operating costs, diesel dependence, and the environmental impact of small grids that run only by diesel power plants. Having the ability to improve system design, evaluate performance, and identify the potential economic benefits of small grids that include renewables will be essential to push these technologies forward. Using Microgrid Modelica library models, it can also be observed that the presence of traditional energy sources such as gas turbines within smart grids provides a source of energy in emergency situations, especially during peak times, as these stations are characterized by the speed of generation and entry to the public grid.

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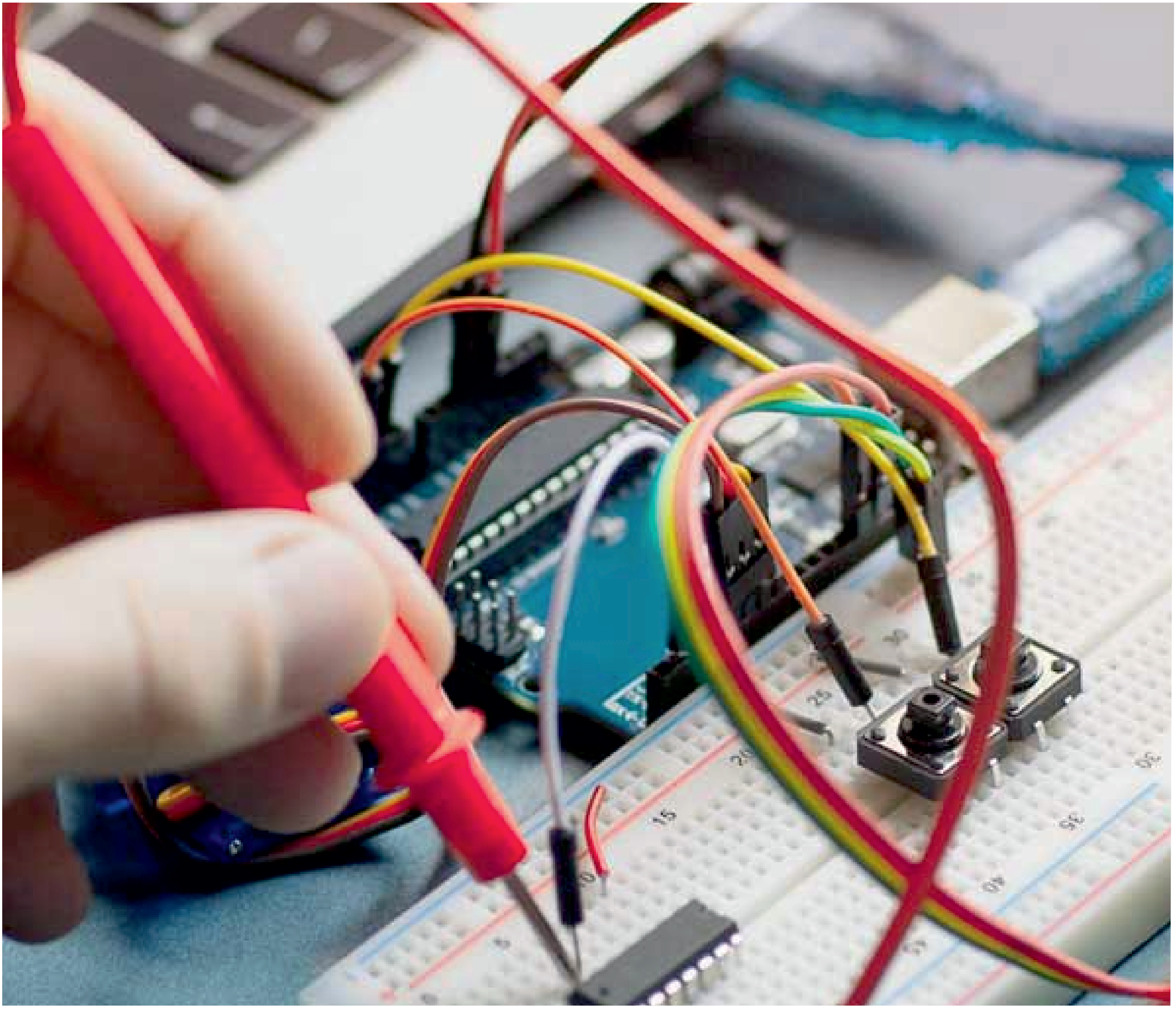

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