DEVELOPMENT OF SIMULATION MODELS IN DISTRIBUTION NETWORK USING ENERGY STORAGE SYSTEMS

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Abstract: Integrating Photovoltaic (PV) systems with battery energy storage will be necessary to allow the continued update of domestic PV system installations. Increasing the environmental and climatic change issues, incorporating sources of renewable energy into power network is the key for the whole world future. To enable voltage control within distribution networks a new application of electrical energy storage (EES) systems and demand side response (DSR) is essential. Modeling and simulation work depends on the operation of control system. A simulation model for DER components in a distribution network, focusing on voltage controllers using energy storage systems for PV penetration is developed. The Vanadium Redox Battery (VRB) system model was implemented in MATLAB/Simulink and Dig SILENT Power Factory to improve the battery efficiency. The simulation results have been validated .an overvoltage controller has also been developed and tested successfully, to study the variability and the interaction between feeders including VRB, PV system and active units.

***Keywords**: Distributed energy resources; PV panels; Smart- Grid; State of Charge (SOC); Vanadium Redox Battery (VRB);*

I. INTRODUCTION

The rapidly decreasing cost of solar photovoltaic (PV) technology in grouping with renewable portfolio standards is driving increased PV deployment in California. In this paper, we go beyond previous analyses by exploring PV diffusion levels of up to 50% in California (with renewable penetration above 66%), and we observe the potential role of storage. Specifically, we observe the amount of storage that may be required to keep PV reduction to acceptable levels. Before evaluating storage, we consider the impact of increased generator flexibility, demand response, exports, and electric vehicles. These processes can greatly increase the potential penetration of PV. It is also important to examine demand response, transmission, flexible generation, and improved operational practices.

In adding together, while there are clear profits of using energy storage to enable greater penetration of wind and solar, it is important to consider the potential role of energy storage in relation to the requirements of the electric power system as a whole. The variability of these sources has led to concerns regarding the consistency of an electric grid that derives a large fraction of its energy from these sources as well as the cost of dependably integrating large amounts of variable production into the electric grid.

- DC-DC buck boost converter based MPPT with normal PWM and SOC method is used to control the PV output.
- SOC controls both input and output of the PV and wind.

- In the voltage controllers one controller is able to control the voltage at the bus-bar charging the battery when an overvoltage is detected.
- The idea was to control the voltage at the bus bar when go beyond the maximum values, due to the PV production, changing the battery mode of operation (discharging/charging).

This paper focuses on simulation models, validated by measurements using experimental capability of an active and spread power systems laboratory, of a small-scale storage system connected to a PV System and a Flex-House with convenient loads at a distribution network. A local voltage controller of the bus-bar to which the VRB was associated is also described. This was also developed and implemented in MATLAB/Simulink and Power Factory, and confirmed through simulations.

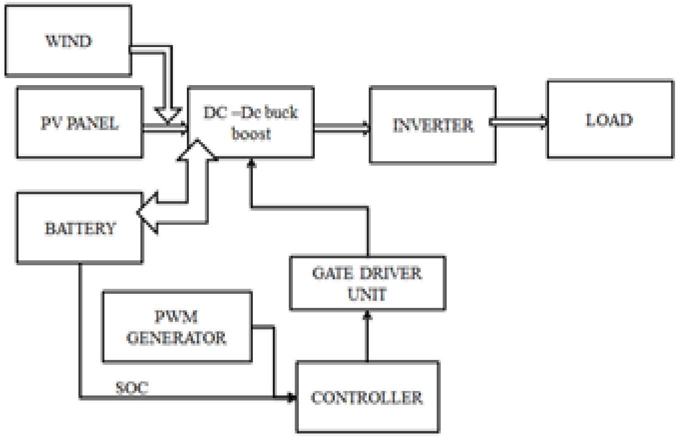

Figure 1.1: Block diagram

The voltages of the PV, wind and battery are different. The dc-dc buck boost converter converts the voltage based MPPT controller with normal PWM and SOC method. When the input voltages reaches maximum level the battery will starts charging. When the input voltages are operate at normal condition the battery will discharge. The controlled voltage transferred in the inverter side and the output of the controlled voltage is given to the distribution network.

II. DISTRIBUTED ENERGY SYSTEMARCHITECTURE. EXPERIMENTAL FACILITY

The SYSLAB is a laboratory for research in scattered control and smart grids with a high contribution of renewable energy production. Its experimental facility is a Wind/PV/Diesel Hybrid Mini-Grid with local storage and a new control infrastructure. It includes two wind turbines (10 kW and 11 kW), three PV-plants (7.2 kW and 2 x 10 kW), a diesel gen-set (48 kW/60 kVA), an intelligent office building-Flex House with convenient loads (10 kW), a number of loads (75 kW, 3*36 kW) and a Vanadium Redox Battery-VRB of 15 kW/120 kWh. The facility is spread across three sites located 700 meters apart, as can be seen in Figure. 2.1). At each of the three sites there is a switchboard that allows the components installed at the site to be connected to either of two bus bars. The components are all associated in one distributed control and measurement system that enables very flexible setup with respect to the experimental conFigureuration [13]-[14].

Figure 2.1: Distributed power system

All units on the grid – generators, loads, storage systems, and the switchgear – are computerized and remote-controllable. The node connect together with an industrial PC, data storage, measurement and I/O interfaces, backup power and an Ethernet switch inside a compact, portable container. The MATLAB flexible control system was used for testing control strategies for the justification of the simulation models.

$$E_{batt} = E_{batt0}+\int P_{cell}.dt$$

Where E_{batt0} is the primary energy stored in the battery and P cell is the charge/discharge power at the electrolyte side.

The state of charge SOC is the amount of energy stored in the battery E_{batt} divided by the total energy capacity ET , plus the initial value of SOC: SOC=SOC0+E_{batt}/ET The internal resistance (R_i) of the battery is a variable parameter and is dependent on the SOC. It was calculated using DC.

The battery system model also includes a graphical user interface (GUI), On the left side are a picture of the battery system and a block diagram of the VRB system, the latter including details of how all components/subsystems have been executed. On the right side are simulation results with DC power (PDC) and DC voltage (VDC), and on the bottom SOC level is plotted as a function of time. Policy and grid operator rules will have a strong influence over DER acceptance and on its successful integration with the grid.

DER technologies are defined as “behind-the-meter” power generation and storage resources typically located on an end-use customer’s place and operated for the purpose of supplying all or a portion of the customer’s electric load. These DERs include solar photovoltaic (PV), combined heat and power (CHP) or cogeneration systems, Micro-grids, wind turbines, micro turbines, back-up generators and energy storage space.

III. DER COMPONENTS MODELING

A. Modeling of a VRB System

The VRB model has been implemented in MATLAB/Simulink and Power Factory and is based on the equivalent electrical circuit and on the power balance between the input and the stored power, which is needy on the efficiency of different components, such as: cell stacks, electrolytes, pumps, power converter and the power losses. The power converter was modeled using a look-up table with values relating to the effectiveness of the AC-DC converter in both charge and discharge operation modes. The total energy stored in the VRB depends on both the SOC and the amount of active chemical substances.

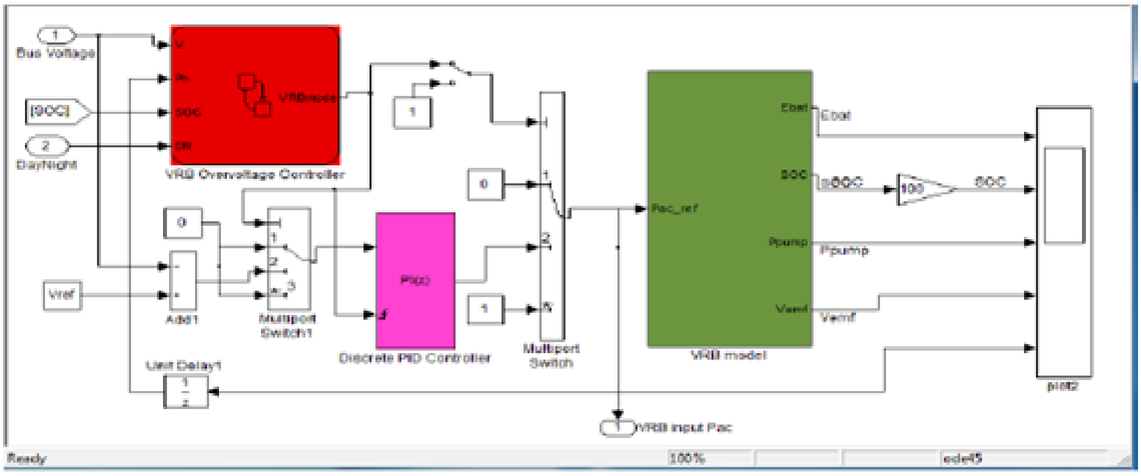

Figure 3.1: Validation of the model

The following experiment for a time scale of 36 hours was considered: starting from a SOC=93.5% the battery was discharged with a constant power PAC=15 kW, until SOC=18%. Then a charge sequence was considered from SOC=14% until the level of SOC=87% at PAC=10 kW. In the course of the discharging cycle a battery constant pulsed current was applied in order to find out the active characteristics.

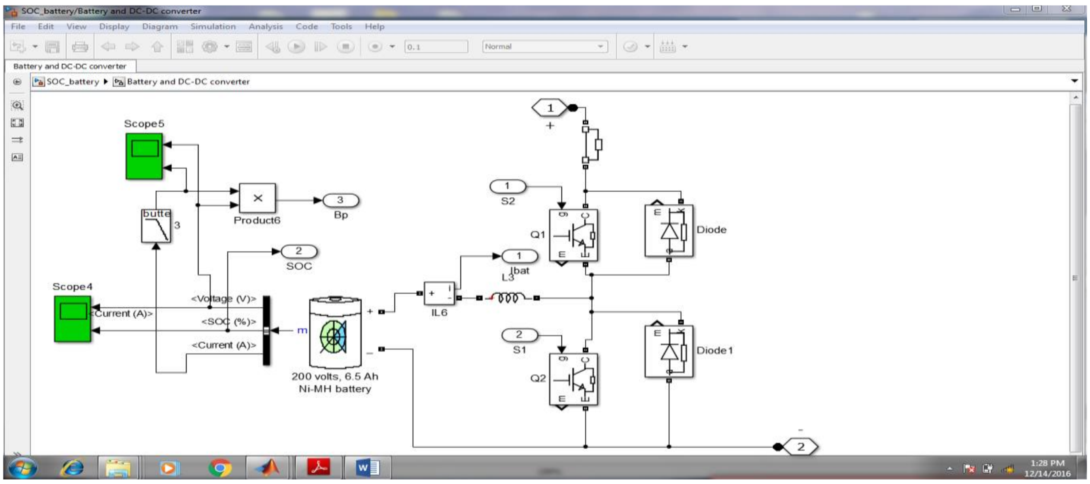

Figure 3.2: Simulink model

A comparison between simulations and measurements of SOC level and DC Voltage and Power is presented as can be seen it is a very small difference between graphics (0.1% at full SOC and 1% under 20% 8 of SOC).

3.2.PV System Modeling

The model of the PV system consist the PV panel's model and the model of the inverter. It has inputs of the irradiation, the ambient temperature and the wind speed, which are converted into cell temperature and irradiation to be utilized as inputs for the model of the panels, and as output the AC power from the inverter

The model takes into account the variation of the parameters (open-circuit voltage and short-circuit current) with regard to temperature and irradiation and also the tilt angle and orientation of the panels. The PV inverter is characterized by a power needy efficiency where the input power of the model is the maximum DC power produced by the panels (which are presented in Appendix).

3.3 Flex-House Modeling

The simulation model of the smart house, called Flex- House, is based on the equivalent electro-thermal model of the building with a stochastic discrete-time linear state-space model combining with physical data regarding heat transfer inside the house collectively with statistical methods to estimate model parameters.

IV. VOLTAGE CONTROLLERS OF THE STORAGESYSTEM

As a part of the power system, the low voltage distribution grid has the objective to provide energy to the end consumer.

The voltage control is a major objective in a distribution network due to a huge number of factors, such as dissimilar load profiles and load types or different number of phases (asymmetrical distribution of DERs in the grid).

Two types of controllers for voltage regulation have been developed and implemented in Simulink based on fixed state machine for managing the bus-bar voltage at the connecting point.
One controller is able to control the voltage at the bus-bar charging the battery when an overvoltage is detected. The suggestion was to control the voltage at the bus bar when go beyond the maximum value, due to the PV production, changing the battery mode of operation (discharging/charging).

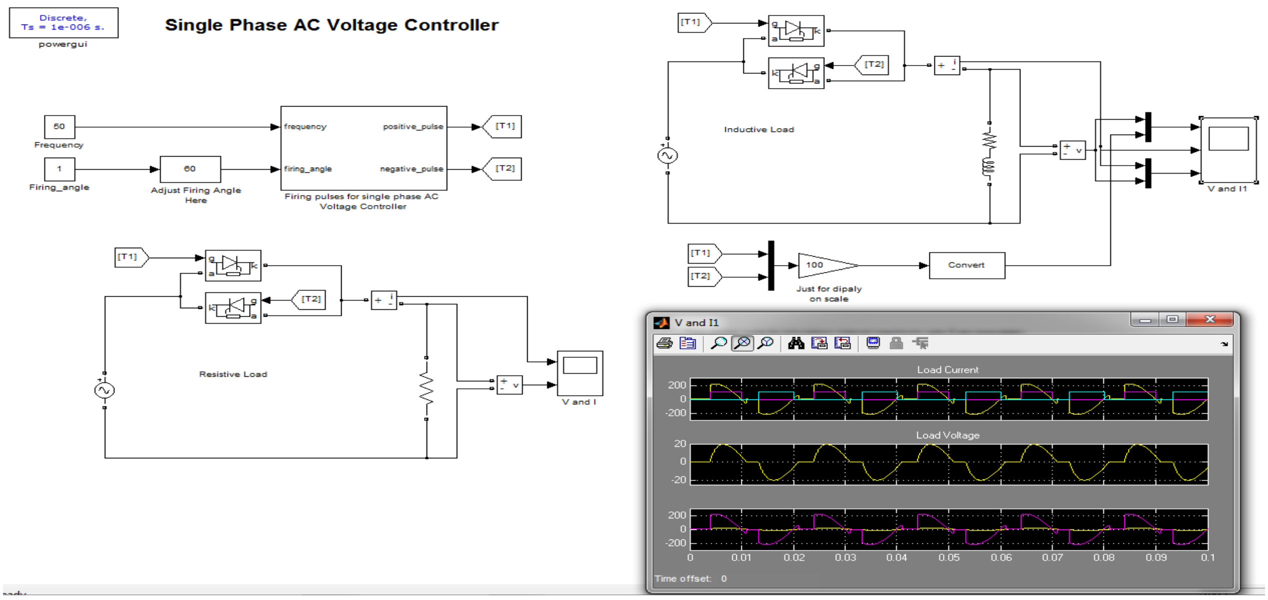

Figure 4.1: VAR model

The objective of this paper is to present novel control strategies for Micro Grid operation, especially in islanded mode. The control strategies occupy mainly the coordination of secondary load-frequency control by a Micro Grid Central Controller that heads a hierarchical control system able to assure stable and secure operation when the islanding of the Micro Grid occurs and in load-following situations in islanded mode.

A MG [1] can be defined as a LV distribution system to which small modular production systems are associated. A MG must also comprise some kind of storage devices (such as batteries or flywheels) as well as network control and management systems.

4.1 Normal Interconnected Mode

The MG will be electrically linked to the main MV network either being supplied by this network (totally or partially, depending on the generation allocation procedures adopted to operate the micro sources) or injecting power into the main MV grid (when the relation between the micro sources installed capacity and the electrical loads allows this type of operation)

4.2 Emergency Mode

In case there is a malfunction in the main MV network, the MG must have the ability to operate in an isolated mode. A simulation stage under the MATLAB® Simulink® environment was expanded in order to evaluate the active behaviour of several micro sources operating together in a LV network under pre-specified settings including interconnected and autonomous operation of the

MG Description of the Simulation Platform To test the effectiveness of the approach considered, a simulation stage under the MATLAB® Simulink® environment was developed. At this step only three phase balanced operation of the network is being measured.

4.3 Microgrid Control Strategies

The main control strategy considered the way to islanded operation mode of the MG in case of a fault in the MV network or in other exceptional cases. Opposing to the classic belief that islanded process must be avoided at all costs, an innovative approach is being developed that includes designed operation under these conditions. The islanding procedure is then controlled and made intentionally, similar to careful preparation about operational conditions regarding not only load levels and levels of the distributed assets but also different types of defaults, etc.MG operation is based on a control scheme that exploits different inverter control modes.

4.4 MG Control and MGCC Structure

The MGCC includes a multiplicity of functionalities one of which is minor load-frequency control. This functionality is similar to the one of a normal Automatic Generation Control (AGC) system. The MGCC coordinates a hierarchical control scheme.

4.5 Secondary Load-Frequency Control

There are two ways of performing secondary load frequency control of the MG: either locally or in a centralized and automatic way, mastered by the MGCC. The load-frequency control is performed as follows: whenever the MG is operating in interrelated mode with the MV network, the vitalized control is disabled; however, when the MG becomes isolated, the MGCC must coordinate the secondary load-frequency control.

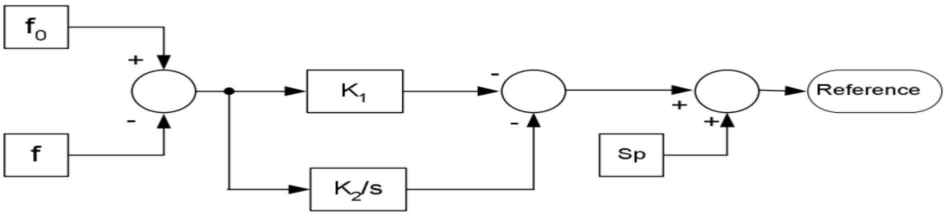

Figure 4.2: Control System Model

The imbalance between load and generation can be caused either by the islanding of the MG or by variations in load or in micro source generation levels [5] (like the ones that result from wind or PV generation). In order to perform load-frequency control, the MGCC receives and stores information from the LCs (load levels) and MCs (micro generation active power levels) and frequency measurements.

The optimal economic set-point (Osp) for each micro source is updated every 60 seconds. These values are entered from a table that contains the results from economic dispatch for a market surroundings. The centralized secondary load-frequency control structure is presented in Figureure

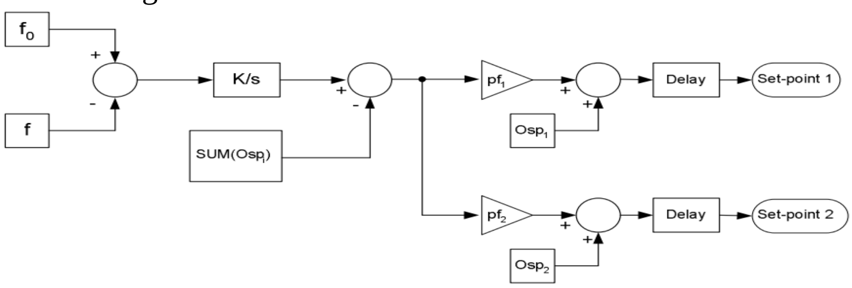

Figure 4.3: Centralized Secondary Load-Frequency Control Structure

B. Simulation results

This section presents three study cases with PV production for 6 days during a summer week. The PV system is connected together with the Flex-House at the same low-voltage bus-bar while the VRB is connected to a different bus-bar at the same distribution grid.

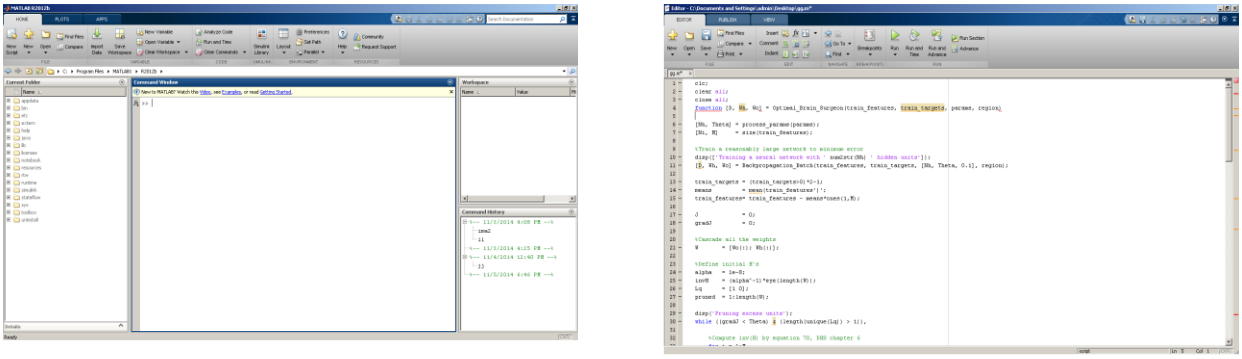

Figure 4.4: Simulation Diagrams

A comparison between voltage at the bus-bar and the maximum voltage, set-up at 1.1 p.u. power production with PV power, Flex-House (Heater) power and the total power injected into the grid, and the temperature inside the house, during normal operation when no controller is implemented. Due to the PV penetration voltage at the bus-bar exceeds the maximum value

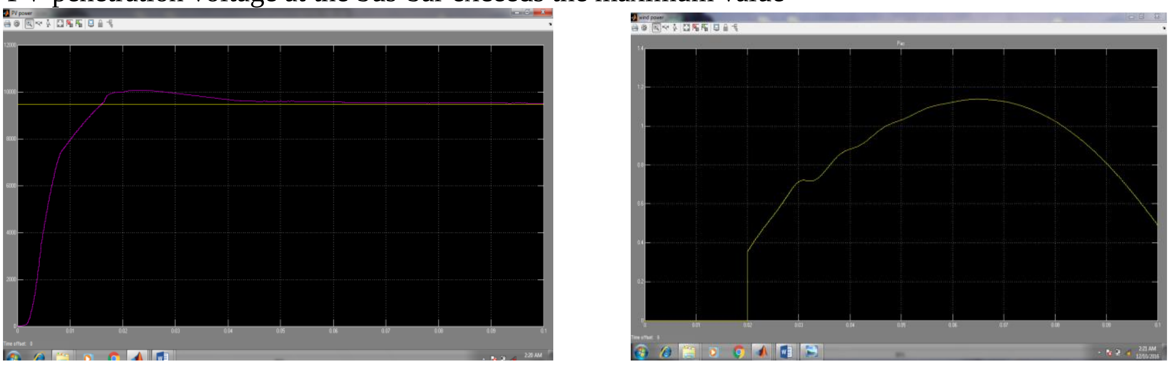

Figure 4.5: Simulation Results

The simulation results for another method to control the voltage using the battery storage system setting the VRB to work in scheduling mode. The battery was scheduled to operate (charged) between 10-18 o'clock during the day, when the PV systems inject the power into the grid, and was discharged during the night. In order to operate in an efficient way in this case the VRB has to be appropriated scheduled of charging itself with the right amount of energy in the middle of the day.

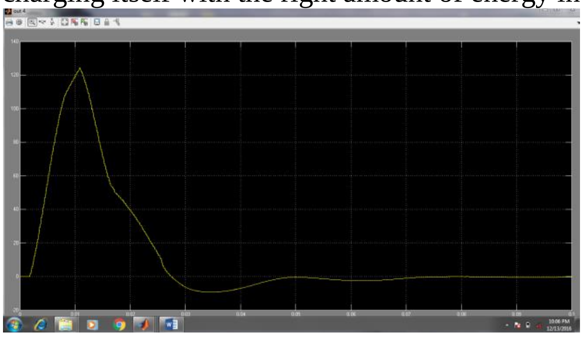

Figure 4.6: Simulation Result for Voltage Control Mode

In this case the VRB's operation is defined as using the voltage control mode during the day, when the PV system is able to produce power, while the battery was discharged during the night. The VRB is connected when an over voltage occurs and it consumes the excess power until the power injected into the grid is not affecting the bus voltage to exceed the voltage limit.

V. CONCLUSION

Such a network of DSLs would involve several form of communication or choice coordination method. Either a micro grid central controller (MGCC), or a dedicated distribution circuit centrally tied to the power plant, would be needed. For remote communities, either solution adds prohibitive cost and/or needless complexity. So called "intelligent loads" have been proposed for frequency support on large grids whereby the idea of two-way communication between the load and the plant is abandoned. Loads instead react directly to changes in the grid frequency error. The concept is extended to micro grids, though voltage error is used as an indicator of load deficit. The present work proposes a novel concept for coordination of distributed secondary loads in an islanded micro grid without the need for an MGCC or dedicated distribution circuit through the use of frequency-responding ETS devices. This study offers the groundwork for a future vision of the isolated wind-powered micro grid in which secondary loads are distributed throughout the community, coordinated only by grid frequency mistake (without the need for a communication infrastructure).

Two techniques for simulating the collective electro-mechanical dynamics of such DSLs are proposed and tested in MATLAB SIMULINK. Frequency and voltage regulation are evaluated with that of a typical system solely under the control of the DEG. The focus of this study is on the responsibility for frequency regulation divided by the distributed loads (ETS units) and the isochronous prime mover (DEG) at a low to moderate level of wind power penetration. Thus, it may be necessary to get better the frequency sensing, controller topology and load switching knowledge of the ETS units. Changes to the design, such as varying the impedance of the elements to a binary scheme would allow for more load resolution. 49 implementation of a PID type controller may also be a necessary advancement. Nonetheless, the goal of a significant reduction in frequency transients is achievable using distributed ETS units in wind-diesel mode.

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