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Interactive Distributed Grid using MATLAB

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Abstract - **The traditional power grid is unidirectional in its operation, where the power is transferred from generating facilities at far flung areas to the users in cities and villages. This system is serving us since few centuries. Lately, it has been suffering from several technical, economic, and environmental issues. Modern society requires this system to be more robust, scalable, and maintainable while also being cost effective, secure, and scalable. The distributed grid is expected to revolutionize power generation, transmission, and distribution by allowing two-way power flows for electrical power. The proposed system is a concept for building scalable distributed systems which consists of generating sources and storage elements with grid-connecting and working in island mode capabilities. This could allow renewable and green energy sources to become mainstream into a controlled utility and achieve higher utilization of existing energy infrastructure. MATLAB/Simulink software is used for simulation and implementation of the design which shows that this approach of controlling distribution of power is simple and effective. The MPPT algorithm used for maximizing power output from solar PV and a modified optimization algorithm which take different constraints for better flexibility is used for battery storage estimation. The operation is mainly focused on variable load scenarios and the response of the renewable generators to operate with variable generation and balancing it with stored energy for variable power demand.**

Keywords — Distributed, Micro grids, Solar Irradiation, MATLAB/ Simulink, Battery, Load, Optimization, Grid

I. INTRODUCTION

In normal power networks, the capability to check power flow and control it in real time is confined to high power networks which use automation systems like SCADA. In the low power networks, the operators have no clarity on who is consuming the amount of power when and how much. Interactive grid allows use of smart sensors and meters which is connected to systems in centrally controlled node, which it makes it possible to monitor & control power flow in real time to every load.

Solar photovoltaic cells are connected forming modules, such modules are attached to form solar arrays. Then are connected to inverter, which produce power. Solar electric power obtained like this forms the primary source of home power needs. Photovoltaic systems which are used in residential scenarios can also be connected to the grid if available, especially in western countries. The grid-connected system has Batteries or additional power storage which are used as stand by in critical applications such as lighthouses, satellites, or in poorer countries as off grid solution. These standalone power systems which use backup storage can facilitate operations at night or during low sunlight.

Lyapunov function related decentralized control mechanism for a single phase parallel-connected inverters system within islanded micro-grid. In this paper voltage regulation (like amplitude & waveform) and power/current sharing is assured even in presence of unknown line impedance & unbalanced LC filter parameters. Higher reliability and robustness need to be ensured since no inter-communication between inverters as well as no centralized controller is implemented, which also gives advantages of scalability and redundancy [1].

Widely used methods for unidirectional power flow control will no longer be effective to analyze renewable energy sources implemented at the consumption sector efficiently. Many strategies are called for to facilitate the bidirectional flow incurred by power production of the distributed energy resource units. The change requires a prudent distribution of automation by means of decentralized management of electric power as well as information and communications technologies to actualize smart grid modernization [2].

For communication assisted dual setting relay protection scheme authors propose the use of dual setting directional overcurrent relays which are capable of operating in both forward and reverse directions along with various settings and with lower bandwidth communication in order to maintain proper coordination. The problem is formulated as a non-linear constrained programming problem where the relay settings are optimally determined to minimize the overall relay operating time for primary and backup operation [3].

Micro grid utilization with distributed renewable energy generation to reduce the burden on utility grids. This enables an energy ecosystem, a cost effective smart micro grid based on intelligent hierarchical agents with dynamic demand response (DR) and distributed energy resource (DER) management. With dynamic update mechanism, DR adapts to user's preference and constantly varying external information. The distributed energy management cooperates the functions of heat/power systems (μCHPs), and vanadium redox battery (VRB) according to DR decisions. A 2-level shared cost-led μCHPs management strategy is made to reduce energy costs further. VRB discharging is managed to be environment-adaptive. [4]

A grid based on photovoltaic and fuel cell sources using renewable energy sources like PV (Photovoltaic) and FC (Fuel cell) may be suitable for small loads but not for large scale industrial application. Although PVFC hybrid system not only produces power that is carbon free but also eliminates the environmental hazards caused by lead acid batteries.[5] But battery technology is moving towards lithium ion and much more safer alternatives. Also, Fuel cell technology is not developing at the same pace as battery cell technologies.

Micro-grids with generation resources are connected to the general power grid to be able to satisfy the variable loads in a cost-effective manner. Micro-grids having generation resources, the bidirectional exchange of power provides additional avenues to optimize performance. This paper describes a new architecture for micro-grid distributed intelligent control and management. The approach followed is based on principles of hybrid systems and optimization. [6]

The gird normally manages energy flow and controls the power, voltage, and may be isolated from the power system or interconnected to the power system at one single point. This single point of connection to main grid called point of common coupling.[7]

In this method the progress is to be in the direction of common types of distributed grid. The control system absorbs the dynamics of system by checking values of few important parameters through sensors and changes the system to achieve the objective of stable supply. The distribution system generally begins at substation, and is fed by multiple sub-transmission lines. Each substation is built to supply primary feeders. Most of distribution feeders are branched, i.e., electricity flows from the substation to the customer.

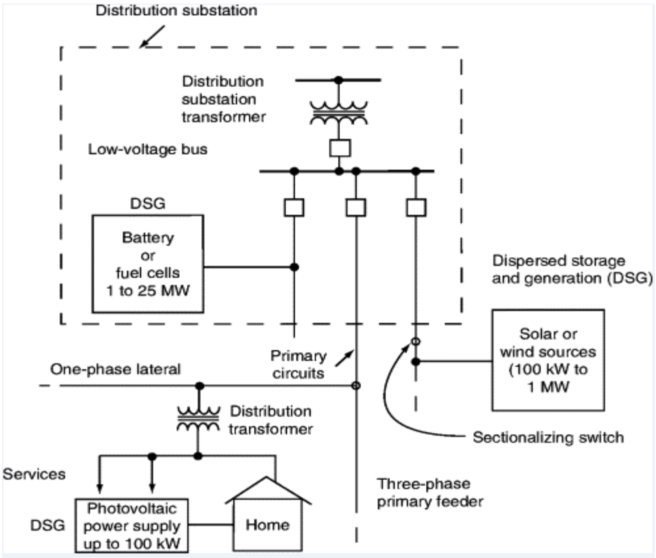

Fig. 1. Structure of Distributed Grid

An average power distribution is comprised of distribution substation which have few feeders. Each of the feeders consists of three phase primary main feeder which branches laterally to 2 phase or single phase. The power lines can be over the ground or below it, depending on viability & requirement. Voltage regulator change voltage parameters, to adjust voltage at nodes to be in standard limits. Some of the primary feeders have in-line transformers so as to supply business customers. Smaller transformers called service transformers supply house customers at 230V. Distribution feeder supplies 1 phase, 2 phase & 3 phase loads depending on the customers like residential user as well as industrial customers.

II. METHODOLOGY

The typical distribution network is always connected to the grid, making it less flexible and largely inefficient to maximize the current technological advancements in renewable and battery technologies. The block diagram is shown in Fig. 2.

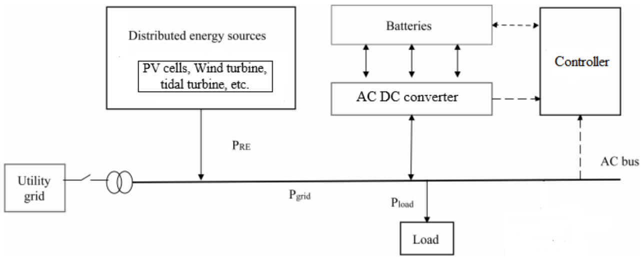

Fig. 2. Block diagram representing methodology

In this block diagram the system can be broken into generators, converters, storage elements and control network.

- Generators

The generators mainly involve Wind/Tidal turbines along with Solar/Fuel cells as well as the main electricity grid which is considered as a generator for the sake of simplicity. These are then connected to converters which convert the voltage to the supply voltage.

- Converters

DC to DC converters, DC to AC converters is used to convert the power to the required value, depending upon the need for storage or usage.

- Storage Element

Battery Banks are the only solution currently but many other Unconventional sources of energy storage is being explored like flywheel energy storage, thermal energy storage, etc.

- Control system

The control system is designed based on the values of Battery voltage, SoC, Irradiation along with the type of customer load behavior.

MPPT Algorithm

Maximum power point tracking (MPPT) is one of the algorithms used in solar PV inverter designs to constantly regulate impedance in the solar array to operate the photovoltaic system nearer to peak power output of solar PV panel under various conditions such as varying solar irradiance, temperature, and load. The flow chart of MPPT algorithm for charge controller is shown in Fig. 3.

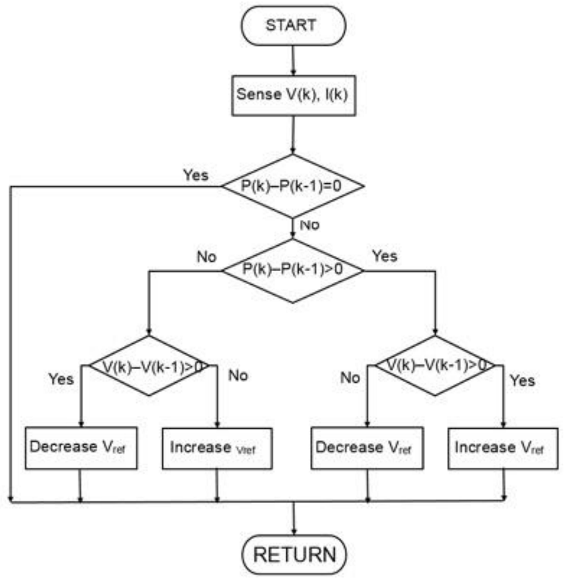

Fig. 3. Flow of MPPT Algorithm

Typically, Perturb and Observe methodology is employed to track the Maximum power point. In this method, a small disturbance is made to have power variation in photovoltaic module. The photovoltaic output is regularly taken & compared with previous output value. If output solar power rises, then process is resumed else perturbation is reversed. The solar module voltage is changed as increased/decreased to see if whether output power is increasing or decreasing. If a rise in voltage points to rise in power, this shows that the operating point of the photovoltaic is left of Maximum power point. So, more perturbation is needed toward right to attain Maximum power point. Similarly, if rise in voltage has decrease of power, this implies that the operating point of the photovoltaic is to the right of the Maximum power point & hence more perturbation in left is needed to reach Maximum power point.

When MPPT controller is implemented across the solar PV module & battery, it takes solar photovoltaic voltage & battery voltages. It checks if battery is completely charged or not. If battery is completely charged, it then stops charging to prevent over charging. If it's is not then it starts charging.

Optimizing Battery

This algorithm handles multiple constraints when compared to usually single constraints. The multiple constraints involved maximum and minimum capacity of solar, Maximum and minimum load. The cloudy and intermittent power outages needed to be taken into account. Finally, the difference between total demand and total solar (renewable) generation is computed to get information on average energy storage needed for particular Load-Solar array configuration. The below Fig. 4 represents the flowchart of the code and the output for particular configuration of generating and load elements are mentioned below.

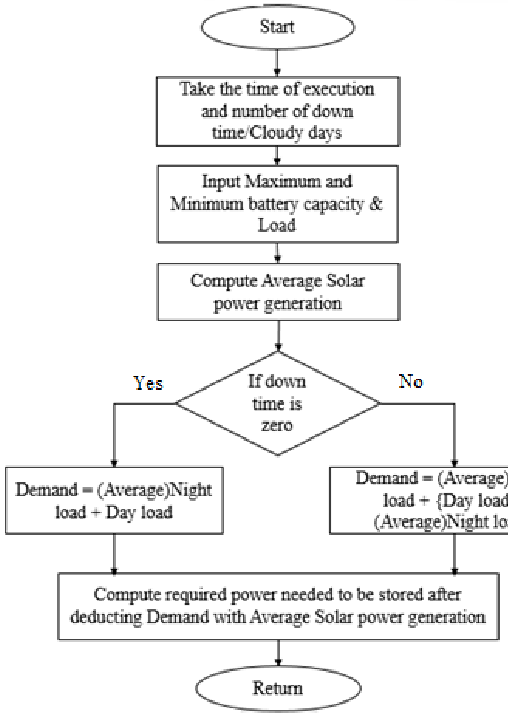

Fig. 4. Flow of Optimum battery computation

III. IMPLEMENTATION

At first, the model requires simulation of solar module, Battery module along with underlying network and Grid. MATLAB/Simulink is used as the simulation software. At first, data of irradiation, Battery type and Load characteristics are obtained. It's then fed to the model which calculates the battery size and corrects itself based on dynamic load conditions simulated in the model.

A. Solar Module

Simscape block interprets solar cell as parallel connection of a current source with two diodes & a parallelly connected resistor Rp, which connects in series with resistance Rs. The cells can be distinguished by short ckt current Isc, open-circuit voltage, Voc & irradiance, Ir0. The following illustration shows the equivalent circuit diagram.

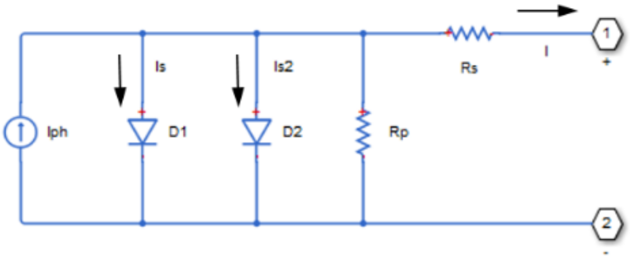

Fig. 5. Solar cell equivalent model
Fig. 6.

Eight solar cells which are connected as series to form string as shown in Figure 5.3, wherein all the irradiance inputs are connected to a common port. Four such strings of solar cells are grouped to make a solar module block. The solar module will have single input, irradiance input & 2 voltage polarity output.

B. Battery Module

The Battery module implements a generic model that represents most widely used type of rechargeable batteries.

This Fig. 5 shows the equivalent model of circuit which the block models.

In order to calculate the voltage, the block implements these equations.

$$V_t = E_m + I_{battery} R_{in} \quad ...1$$

$$SoC = \frac{1}{Cbatt}\int_0^t Ibattdt \quad ...2$$

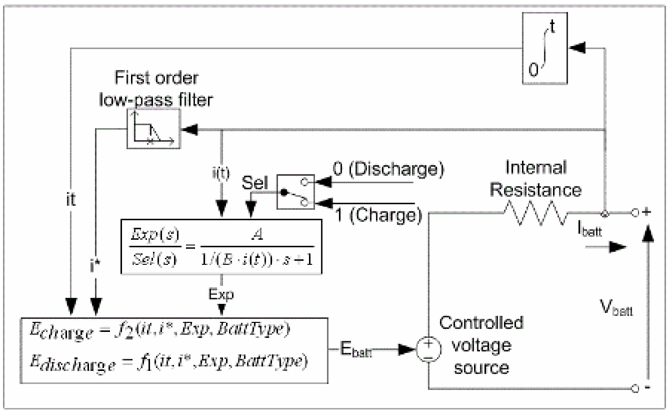

Fig. 7. Battery equivalent model
Fig. 8.

The state of charge (SOC) of a battery is typical measure of battery's charge, expressed as a percent of the full charge. The depth of discharge (DOD) is the numerical compliment of the SOC, such that DOD = 100% - SOC.

C. Intermediate Results

In this simple model, the solar PV supports and recharges the battery as long as the irradiation is above critical level. As irradiation is directly linked to solar power generated. Whenever the irradiation falls below it the battery supplies the power to the load.

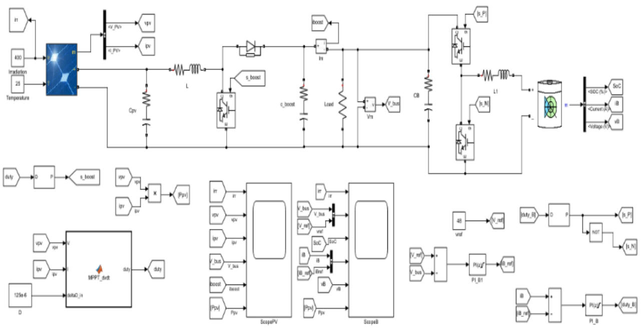

Fig. 9. SIMULINK model of Grid separated Distributed grid
Fig. 10.

The mean irradiation required below which the battery starts to discharge to the load is about 320 W/m2. Above this value, the PV starts to supply the power to the load along with simultaneously recharging the battery. Below it the PV cell alone can't supply the required power and it's substituted by the energy stored in the battery.

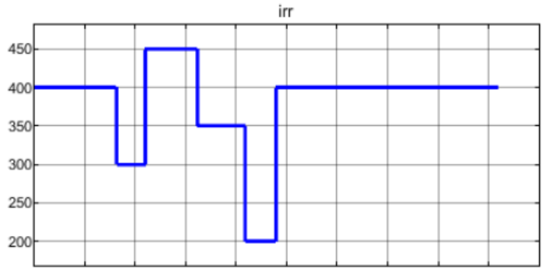

Fig. 11. Irradiation levels on Solar PV Cells

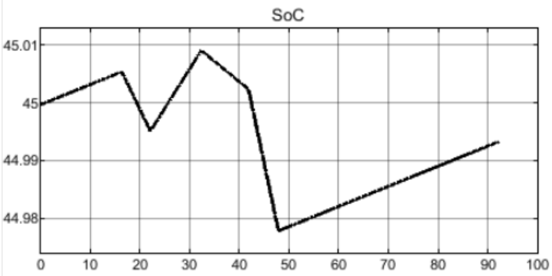

Fig. 12. Battery SoC

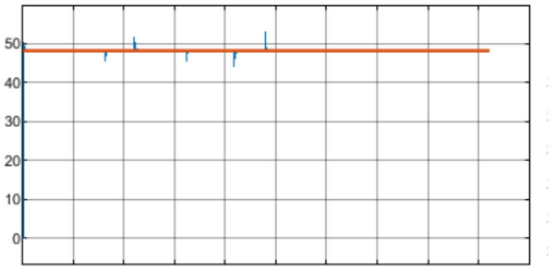

Fig. 13. Load Voltage

D. Implementation of Grid Connected Interactive Distributed Grid

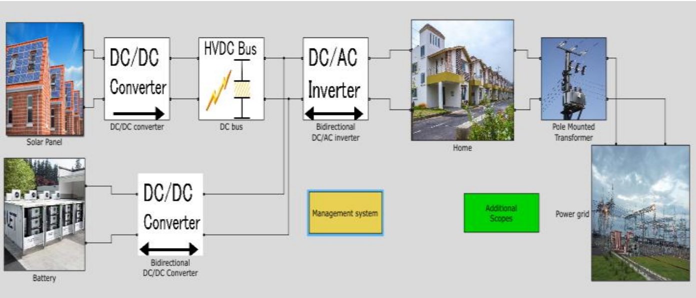

Fig. 14. SIMULINK model of Grid connected interactive Distributed grid

The distributed generation model is simulated as shown in Fig. 11, with different values of Load in a particular time limit, and load voltage, grid power along with battery SOC is monitored. By varying the load, model exhibits the distributed grid being completely in island mode and connected with grid. This model is connected with the grid and is simulated in both modes.

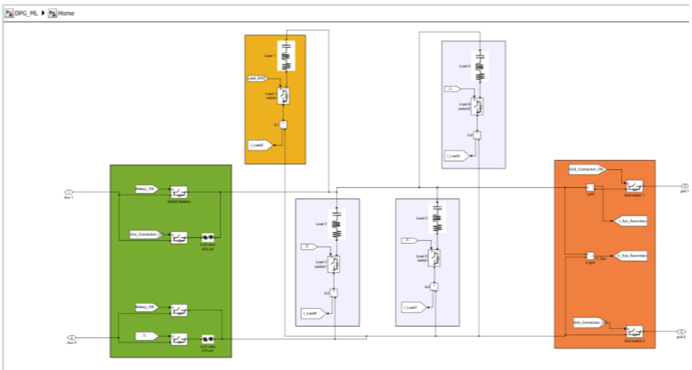

Fig. 15. Loads of Grid connected Distributed grid

IV. RESULTS AND DISCUSSION

The below results are for multiple nodes containing variable demand characteristics. The switches across the load SW1, SW2, SW3 and SW4 respectively are enabled at different intervals describing dynamic multiple load scenarios. The model is made to run in 2 separate modes Grid connected mode and Grid disconnected Mode. In Grid mode the entire demand is satisfied by the grid, whereas in island mode it's supported by PV array and Battery.

The power across the loads is fairly constant and is similar to the behavior in the grid mode. Whenever the load is less on the system, the PV system is sufficient to supply the load along with surplus power used to charge up battery. If the load is higher, then battery starts to support the PV system and starts discharging, one can see this in Fig.14. Below Fig. 22 is the output when the simulation of multiple loads case is done by increasing loads from 4 to 6. We can observe that the system behaves normally.

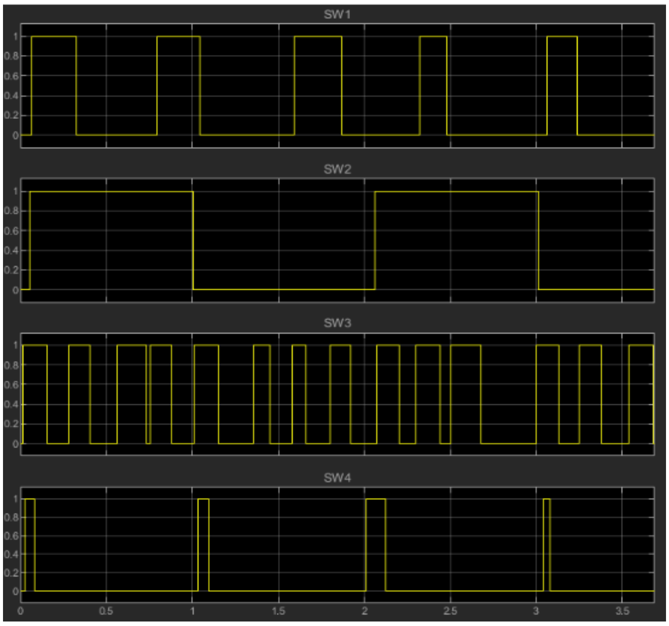

Fig. 16. Switching duration of the respective loads

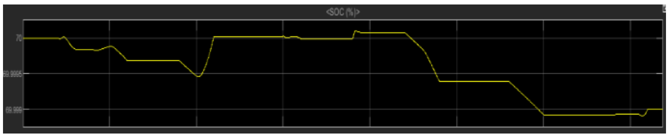

Fig. 17. Battery SoC

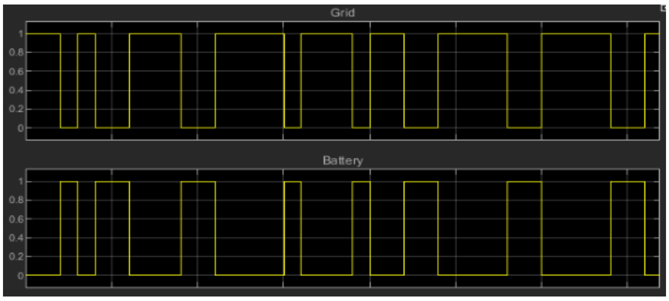

Fig. 18. Modes of Operation

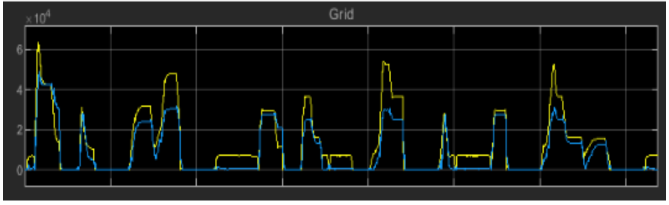

Fig. 19. Grid Power

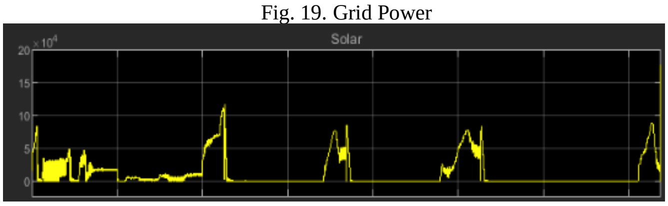

Fig. 20. Solar Power

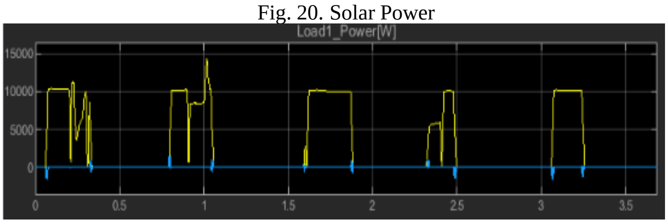

Fig. 21. Load 1

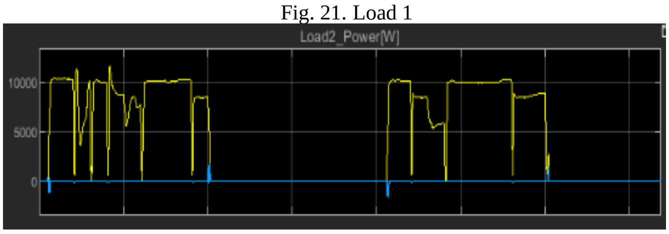

Fig. 22. Load 2

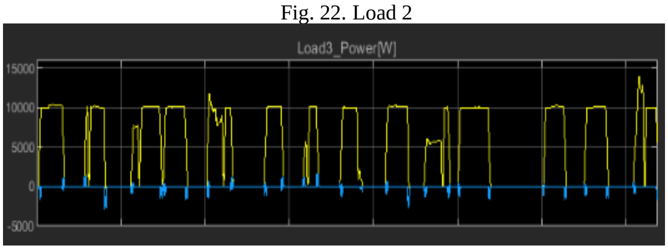

Fig. 23. Load 3

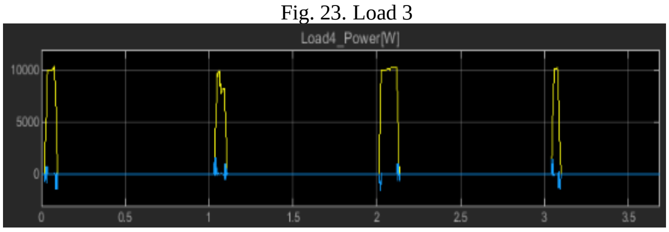

Fig. 24. Load 4

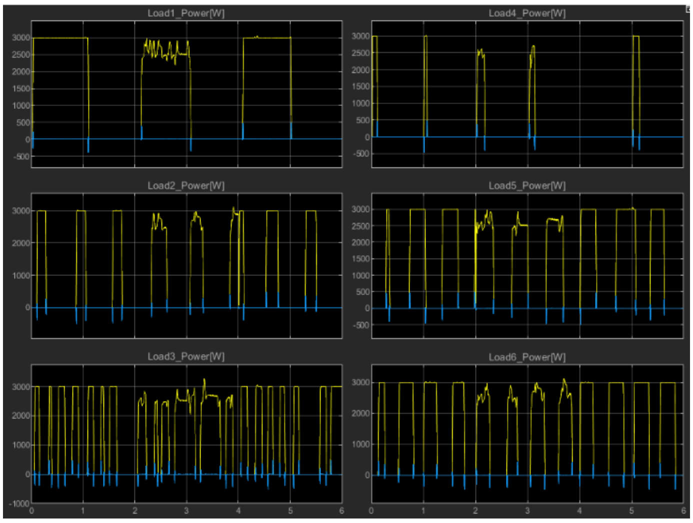

Fig. 25. Load Voltage behavior for 6 Loads

V. CONCLUSION

This paper talks about Simulink model of Interactive distributed grid using MATLAB. In both the modes and also in multiple power demand scenarios the system behaved as expected and switched to and from island mode seamlessly without any major performance degradation. The method proposed does not involve any complex sub systems. It uses basic parameters to effectively control the typical distributed grid. Thereby eliminating the higher hardware costs and this method also is scalable to a reasonable size to typically few tens of loads. The future scope is to reduce cost of the subsystems like battery and PV array need to be considered to arrive at efficient size of a distributed grid for maximum performance. And various other factors like temperature, humidity and weather patterns need to be analyzed, since performance of battery and solar arrays or any renewable sources are especially erratic during harsh weather conditions.

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