

Agent Based Load Management for Microgrid

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Abstract—High penetration of distributed generation leads to the importance of adapting the new trend of Smart Grid to divide the grid into intelligent Micro-Grid zones and facilitate its operation using decentralized distributed control schema. In this paper a practical Microgrid model has been designed and simulated using MATLAB/SIMULINK (MATrix LABORatory). JADE (Java Agent DEvelopment Framework) platform was used to design an agent-based control system that uses a certain algorithm to control both of the load and the supply units by switching on and off the breakers according to specified power reliability criteria. TCP/IP (Transmission Control Protocol/Internet Protocol) protocol was used to link the SIMULINK environment and the JADE Platform. Simulation of typical daily scenarios were tested to verify the effectiveness of the control system.

Keywords—Microgrid, photovoltaic system, Multi-Agent System, Matlab, S-Function.

I. INTRODUCTION

The increasing demand on the power grid makes the dependency on large central generation units infeasible due to the cost and the losses in the transmission lines. Given the challenges facing the grid of today, distributed generation (DG) has been widely seen as an opportunity to facilitate the planning, management and security of the distribution network [1]. The Micro Grid (MG) concept assumes a cluster of loads and micro-sources operating as a single controllable system that provides both power and heat to its local area. This concept provides a new paradigm for defining the operation of distributed generation [2]. MG is a localized grouping of distributed energy resources (DER) and controllable interconnected load all connected to the grid through single point of common coupling and can operate either connected to the grid (connected mode) or isolated from the grid (Islanded mode). The division of power grid to multiple MG will help to reduce the overall overhead of controlling the grid from central control unit and also each MG can contribute in reducing the peak demand by shifting or even satisfying its load with the local generation which help in reducing the cost of running the central generation in its spinning reserve limit [3].

Agent technology has been the subject of extensive discussion and investigation within the scientific community for several years, but it is perhaps only recently that it has seen

any significant degree of exploitation in commercial applications. Multi-agent systems are being used in an increasingly wide variety of applications, ranging from comparatively small systems for personal assistance to open, complex, mission-critical systems for industrial applications. Examples of industrial domains where multi-agent systems have been fruitfully employed include process control, system diagnostics, manufacturing, transportation logistics and network management [4]. An agent can be defined as a software entity that has certain goals, which it tries to achieve, certain capabilities which it possesses, certain knowledge which it has, and is autonomous in respect of its actions. By autonomy we mean that an agent can operate usefully at its own without any intervention from outside world and it has control both of its internal states and behavior. Agent based programming can be considered as a logical extension of programming methodologies and it can be viewed as a specialized form of an object where no one from outside world can change its state, or as a particular form of a component [5].

These days, intelligent agent based control is an effective way to monitor and control the system operations in different conditions [7]. In [8 and 9], the author discussed the criteria of multi agent system in electrical power applications. The design and implementation of multi agent systems in Microgrid using JADE platform is being illustrated in [10]. An architecture of MAS using TCP/IP is proposed in [11,12,13].

In this paper an agent is designed based on Java Agent Development Framework (JADE) to function as load operator who monitors the available generation and the needed demand to decide which load to turn off based on priority. The SIMULINK model represents the physical grid while JADE agent represents the control device that manage the demand-supply operation. The connection between these two parts is implemented via TCP/IP communication protocol.

II. MICROGRID DESIGN

The Micro Grid is a selected area that has distributed generation able to satisfy the local load. Al-Kobbaneya, part of Shambat district in Khartoum (Sudan), is the selected area to design MG, because it has low load profile that can be coordinated to operate independently of the national grid. The MG is shown in Fig. 1 connected with utility grid (represents the rest of Sudan network) implemented in SIMULINK.

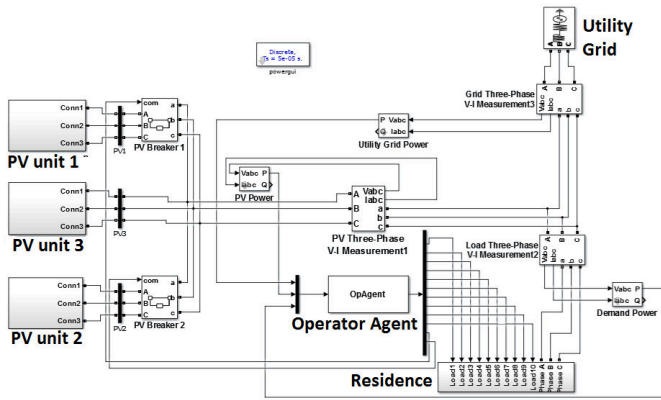


Figure 1: Microgrid Model in MATLAB/SIMULINK.

The model of the system is composed of the following parts:

- Distributed Generation, this part of the system is composed only of Photovoltaic (PV) farms. Solar generation is considered the most suitable and feasible renewable energy source for Sudan due to the high solar exposure in Sudan. In Fig. 1 three subsystem blocks are shown, two controllable PV units with breaker and one PV unit without breaker.
- Residential Load, this part represents the load of Shambat Al-Kobbaneya feeder.
- Control Center (or Control unit), this part represents the Operator Agent that control the load and the two controllable PV units, which is the physical Agent.
- Utility Grid, this part represents the rest of Sudan National Grid side.

A. PV Subsystem

MATLAB has an embedded PV Array block implements an array of photovoltaic modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series. Each PV unit was sized to provide 728 KW according to the following steps:

1. The power demand (Watt-hour per day) is determined.
2. The total demand Watt-hours per day for each unit is multiplied by 1.3 (accounting for energy loss in the system of 30%).
3. Because the peak Watt produced also depends on climate of the location, the total Watt-hours per day required from the PV units are divided by the value of insolation incident to get the total rating needed for PV panels to supply the demand. The worst case of monthly average insolation incident, which is solar irradiance integrated over time, is found from the data for solar exposure around the world and used to determine the total rating.
4. The required power generation (β) is divided by the rated output Watt-Peak of the used PV module (ρ). The fractional part of the result is rounded up to the

next full number to give the total number of PV modules required (η).

$$\eta = \beta \times 1.3 / (\chi \times \rho) \quad (1)$$

$$\eta_s = V_{dc} / V_{mpp} \quad (2)$$

$$\eta_p = \eta / \eta_s \quad (3)$$

Where χ is worst case monthly average insolation incident, η_s is the number of series modules, η_p is the number of parallel modules, V_{dc} is the DC Link voltage, and V_{mpp} is the voltage at maximum power point.

Subsystems internal structure is shown in Fig. 2. The inverter and the DC-DC converter with their controllers were taken directly from MATLAB 400-kW Grid-Connected PV Farm (Average Model) example to provide maximum power output to the Microgrid.

The attenuation of the LCL-filter is 60 dB/decade for frequencies above resonant frequency, therefore lower switching frequency for the converter is used. It also provides better decoupling between the filter and the grid impedance and lower current ripple across the grid inductor. hence, LCL-filter fits perfectly in this system. The cut-off frequency of the LCL filter can be calculated using the formula:

$$f = \frac{1}{2\pi} \times \sqrt{\frac{L_g \times L_i}{L_i \times L_g \times C_f}} \quad (4)$$

Where f denotes the resonance frequency, L_g denotes grid side inductor, L_i denotes inverter side inductor, and C_f denotes the filter capacitor. These filter components were designed following the steps in [6].

B. Residential Load

Typical load data of Al-Kobbaneya feeder were taken from the Control and Research Center of Shambat. The data represents the transformers connected to the feeder along with

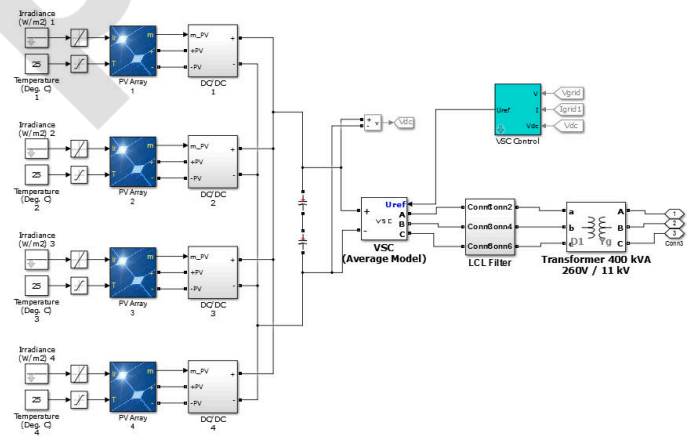


Figure 2: Photovoltaic Subsystem.

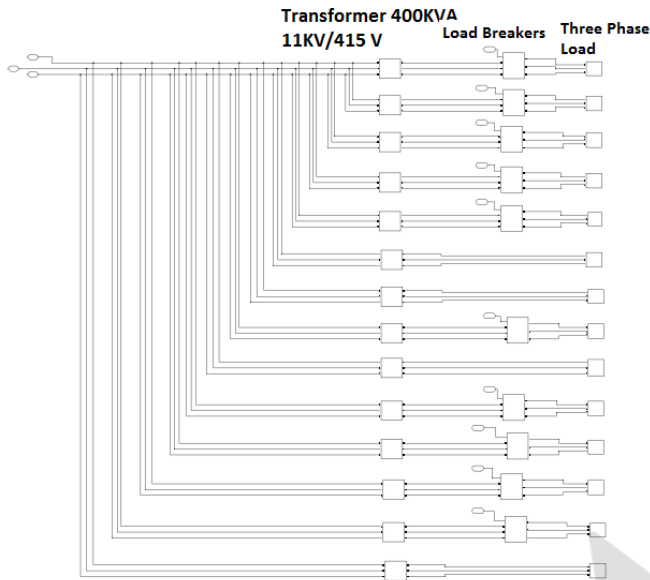


Figure 3: Residential load structure.

their linked load. This data is modeled in SIMULINK using three phase load connected with transformer 11 KV/415 V to convert the voltage to the distribution level 415 V. Fig. 3 shows the internal structure of the Residence block. Four of the fourteen loads have no circuit breaker, because these loads are considered very essential loads and can't be switched off by the control.

III. AGENT DESIGN

The agent is designed based on Java Agent Development Framework (JADE), that is suitable for designing decentralized control by introducing multiple agents with dedicated goal who can interact and negotiate with each other's, forming Multi Agent System. The Operator agent class implements simple algorithm for load shedding to prevent generator overload and under voltage conditions. The agent measures the generation power and the demand power to check if the load power is greater than the set limit for the generation power. If the demand power is greater, then it will start shading the load according to a given load priority. Fig. 4 shows the agent algorithm. Typical agent has many features, behaviors and protocols to communicate but due to the simplicity of the algorithm, only cyclic behavior is used to handle the operations of the agent.

In Fig. 4, shedding represents a counter for the disconnected load, P_l represents the load power (demand power), P_g represents the generation power, PPV represents the power of one PV subsystem (728 KW), and PSL represents the estimated power of the disconnected load.

Based on the algorithm, the Operator Agent class was created, an instance of the class, named `Operator_Agent`, is shown in Fig. 5 in JADE GUI running in the main container. The rest of the agents perform managing operation to the platform and the GUI.

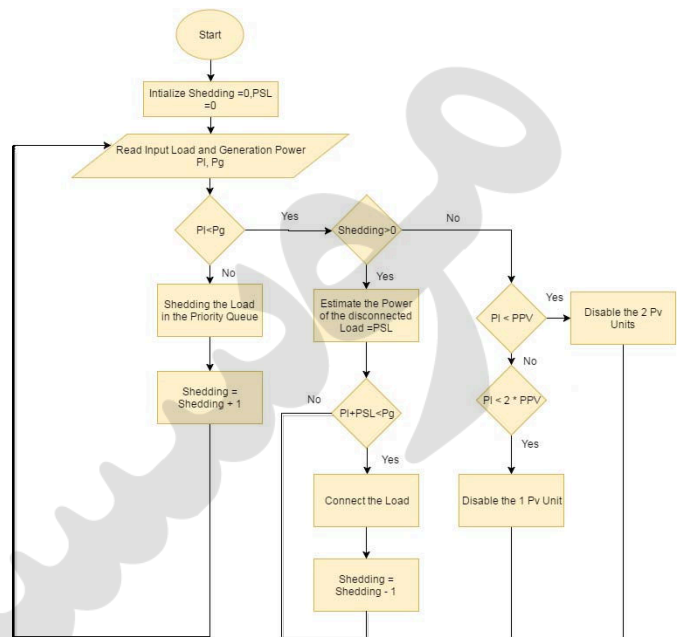


Figure 4: Agent Algorithm.

IV. TCP/IP CONNECTION

Simulink model represents the real physical grid, JADE agent represents the real load operator center, the connection between this two part is via network communication line or power line in reality, this communication should be secure and reliable, thus, the implemented connection to integrate between Simulink and JADE is TCP/IP communication. A socket is made to link the two side, the Simulink represents the Client side, which sends the generation and load power, and JADE represents the Server side, which receives the power and replays with the statues, on or off, of the load breakers required to satisfy healthy operation conditions and the status of the two controllable PV units.

JADE implements Java Server Socket to communicate with the client through specific port. MATLAB also implement TCP IP object for communication, but in order to provide dynamic communication with the SIMULINK environment, which preform certain specific order of steps to calculate each

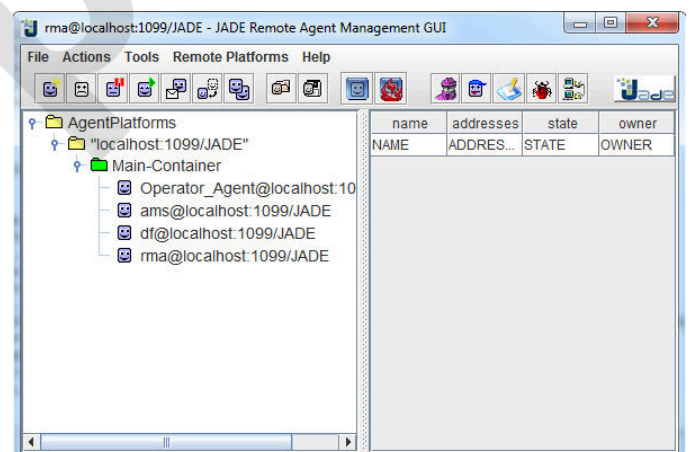


Figure 5: JADE GUI.

block and its output, a special block, called S-Function (Script Function), is used to provide the dynamic communication with JADE. In the initialization step the connection is established with JADE and in each update the data is sent and received from the buffer. Of course JADE need to be running first before compiling the SIMULINK model and when terminating the simulation, the S-function destroy the Socket. The S-function is shown in Fig. 1 as a block named Operator Agent (OpAgent).

V. TESTING

Two testing scenarios were used to evaluate the agent performance. The voltage level, the breakers status, the demand power, the output power from the PV units, and the output power from the utility Grid are shown for each scenario to reflect the action taken by the agent. The first scenario tests the agent ability to keep the power under a certain level, whether it requires shedding or no action. The second scenario examines the ability of the agent to detect the conditions when some of the PV units are no longer required and can be switched off.

A. Normal and Shedding Scenario

This scenario mimics the normal daily load profile in the selected area. First the demand starts at 1.9 MW, after a while it reaches the peak at 2.6 MW and then goes down again to 1.9 MW. In this scenario the agent is given 2.18 MW as the limit to keep the power under it, i.e the Microgrid is supplied only using the PV capacity and that the utility grid is unable to give any additional power.

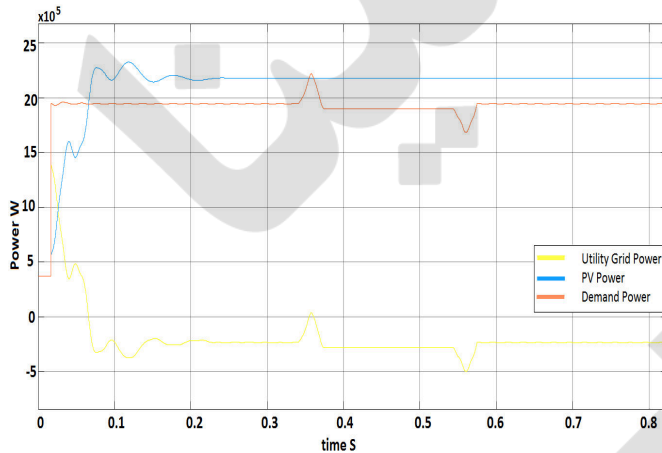


Figure 6: Plot of the measured Power during scenario 1.

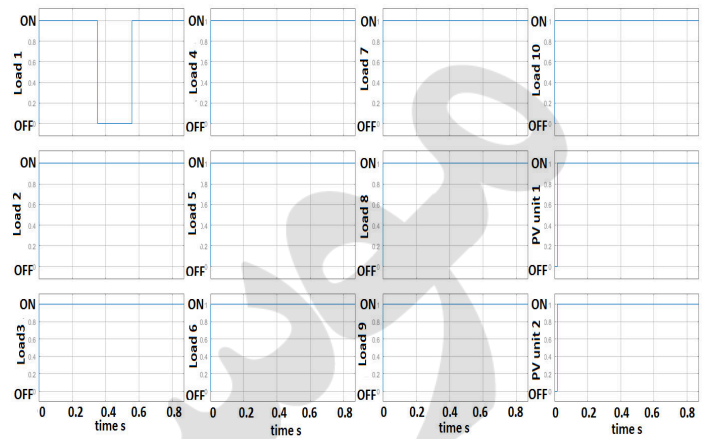


Figure 7: Plot of the breakers status during scenario 1.

As shown in Fig. 6, the PV units has a short transient state last only for 0.2 second and then it gives a constant output power despite the change in the load while the utility grid output power changes with the load power and the PV power; because it acts as a swing generator. First the conditions are normal and the agent doesn't act, but when the load increases to more than 2.18 MW the agent immediately cuts off the first load which has the least priority as shown in Fig. 7. Then when the load is decreasing by a suitable amount, the agent connected the load that has been cut safely without exceeding the defined limit of power.

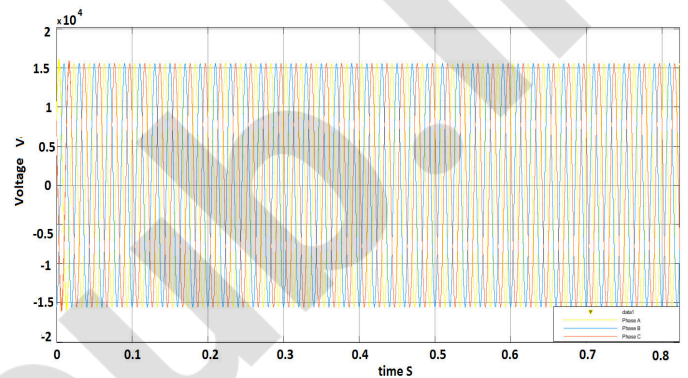


Figure 8: Plot of the Voltage level during scenario 1.

```
<terminated> Start [Java Application] C:\Program Files\Java\jre1.8.0_74\bin\javaw.exe
The Demand Power = 1946904.9937
Power Exported to the grid = 232853.7021
Power Generated from the PV = 2179758.6958
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:on PV Unit 2:on
The Demand Power = 1946864.9405
Power Exported to the grid = 232892.4338
Power Generated from the PV = 2179757.3743
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:on PV Unit 2:on
The Demand Power = 1946824.0682
Power Exported to the grid = 232932.1752
Power Generated from the PV = 2179756.2434
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:on PV Unit 2:on
The Demand Power = 1946782.4176
Power Exported to the grid = 232972.8889
Power Generated from the PV = 2179755.3065
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:on PV Unit 2:on
```

Figure 9: Agent measurement and output during scenario 1.

The stable voltage level shown in Fig. 8 indicates that the agent operation is safe and doesn't affect the system stability. Shown in Fig. 9 the agent screen that shows the exact instantaneous measured power and whether currently the power is exported (negative) from the Microgrid to the utility grid or it is imported (positive) from the utility grid to the Microgrid and its exact amount, along with the breakers' status.

B. PV units Control

This scenario tests the agent ability to control the two controllable PV units when the load is very low that only two PV units are required and also when one PV unit is enough to satisfy the load. At first the load is 1.7 MW then it drops to 1.3 MW and decreases further to 1 MW until it reaches to 309 KW.

Shown in Fig. 10 and Fig. 11 that the agent was able to examine first the condition of no shedding in order to start controlling the PV units, and when the demand dropped below the capacity of two units or the capacity of one unit, the agent switched off one unit or two units respectively. Also shown in Fig. 12 the voltage signal which indicates that it's a stable operation.

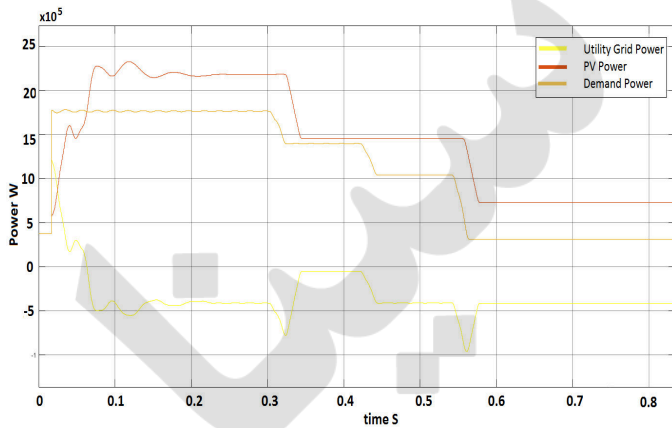


Figure 10: Plot of the measured Power during scenario 2.

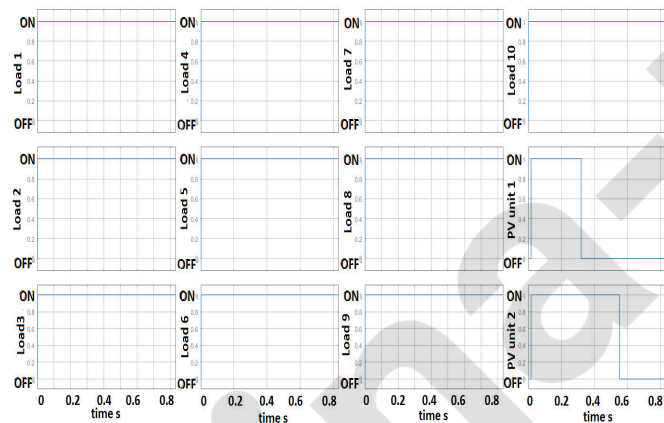


Figure 11: Plot of the breakers status during scenario 2.

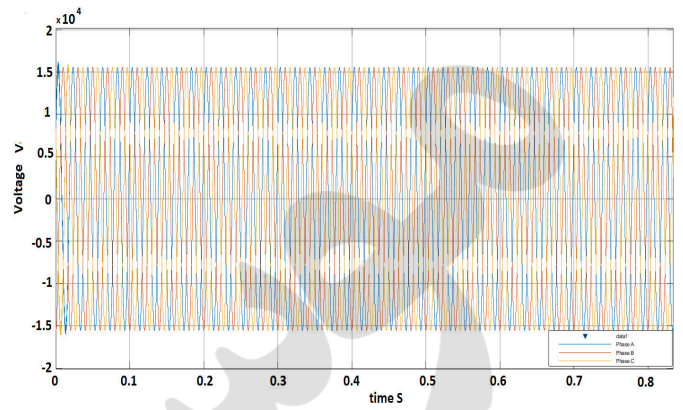


Figure 12: Plot of the Voltage level during scenario 2.

```
<terminated> Start [Java Application] C:\Program Files\Java\jre1.8.0_74\bin\javaw.exe
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:off PV Unit 2:off
The Demand Power = 309541.3912
Power Exported to the grid = 417331.2228
Power Generated from the PV = 726872.614
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:off PV Unit 2:off
The Demand Power = 309531.6502
Power Exported to the grid = 417340.3478
Power Generated from the PV = 726871.9979
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:off PV Unit 2:off
The Demand Power = 309522.1392
Power Exported to the grid = 417349.2781
Power Generated from the PV = 726871.4174
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:off PV Unit 2:off
The Demand Power = 309512.8675
Power Exported to the grid = 417358.0049
Power Generated from the PV = 726870.8724
B1:on B2:on B3:on B4:on B5:on B6:on B7:on B8:on B9:on B10:on PV Unit 1:off PV Unit 2:off
```

Figure 13: Agent measurement and output during scenario 2.

Shown in Fig. 13 the final statuses of the breakers are connected and the two PV units were both turned off.

VI. CONCLUSION AND FUTURE WORK

The Microgrid is the key for the future Smart Grid design. The proposed model for Microgrid was designed using real load data of Al-Kobbaneya zone in Khartoum, Sudan. A proposed Photovoltaic system for the area was designed, seized for suitable capacity and harmonic elimination was done by a properly design of LCL filter compatible with the network. An Agent was created using JADE platform to preform simple load shedding algorithm and PV units control depending on the demand power and the specified power limit. The priority algorithm satisfied to serve critical loads and vital points in the Microgrid, but also found to be unfair for the load with the least priority. Testing scenarios were carried to validate the agent actions and found to be effective and doesn't affect the system stability and the voltage signal. TCP/IP connection proved to be suitable for the application, provides real time data exchange, beside the ability of its physical implementation.

For an interested reader, future work is to investigate further in the Microgrid modeling, like including more design details as the lines impedance from the feeder to the loads and to simulate the daily irradiance and temperature variance in the selected zone. Multi Agent System is a powerful technique when many Agents contribute in the decision making, and so introducing dedicated agents for generation control would potentially increase the system performance and generation

optimization. It would also be beneficial to apply the proposed agent algorithm for small house scale control to allow demand side management and negotiation between house agents to contribute in flattening the overall load profile without cutting an entire neighborhood. Extra work to improve the load shedding satisfaction can be done through more investigation in the agent load shedding algorithm, as in the work of [14].

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