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Research Article

Intelligent Load Shedding Strategy based on Fuzzy Logic Control (ILSF)

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Abstract

Microgrid (MG) is a new form of electrical power grid, combined from different Distribution Sources, MGcan work as a power source or power load in two different operation mode: grid-connected mode and stand-alone mode, one of the main challenges which can be faced in the stand-alone mode is achieving the power balance between the produced power by MG sources and consumed power by MG loads, Load Shedding (LS) is a strategy which can be used for accomplish that balance. This paper emphasis an Intelligent Load Shedding based Fuzzy Logic Control (ILSF), Due to the benefits of Fuzzy Logic Control (FLC), it's used for controlling the shedding process of different MG loads according to the Solar Power Forecasting Data. The proposed control system procedures are illustrated and simulated, the results demonstrate the robustness and flexibility of ILSF system.

Keywords: Load management; Load shedding, Microgrid, Power system control; renewable energy

Abbreviations

MG: Microgrid.
SMG: Solar Microgrid.
DG: Distribution Generator.
RES: Renewable Energy Sources.
ESS: Energy Storage System.
SMG-FD: Solar Microgrid Forecasting Data.
PLS: Percent of Load Shedding.
MGCC: Microgrid Central Control.
ILSF: Intelligent Load Shedding Based Fuzzy Logic Control.
PCC: Point of Common Coupling.

Introduction

Due to exponential increase in global energy demand, there is a rapid depletion of fossil fuels and, the greenhouse emissions have been increased. To overcome these problems, the Renewable Energy Sources RES have been deployed on a large scale in the power system to meet the increment of the energy demand, and reduce the environmental pollutants [1], in addition of Renewable Energy befits, it has so far been the energy source most resilient to Covid-19 lockdown measures [2], and a Microgrid strategy is the best

strategy that can provide the smart interface of the RES in the power system and provide an intelligent automation for these sources to get an optimal use of it in secure, reliable, and coordinated ways [3, 4].

The MG have a lot of definitions have been mentioned in many researches, all of these definitions agree on that MG is a bounded power grid, which contains a set of Distributed Generators (DG) for feeding a set of different loads: controllable and non-controllable loads in a limited area, such as a building, city, factory or military base [5], these DGs may include different forms of electrical energy such as: Renewable Energy Sources (RES) like a wind power or solar power etc., or nonrenewable resources (conventional methods) like Disel Generator, and Energy Storage System (ESS) which works as a backup system like Battery or Super capacitor, etc., The schematic of MG is depicted in Figure 1.

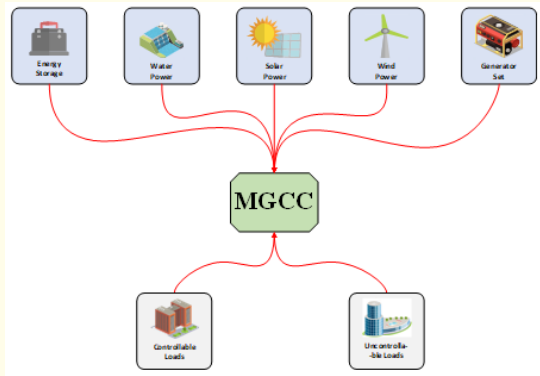

Figure 1: schematic of Microgrid (MG).

The MG can operate as a power load or an independent power source in two operational modes, which is grid-connected mode and stand-alone (isolated or island) mode [6] as shown in Figure 2, in grid connected mode, MGcan be tied to the main grid by the Point of Common Coupling (PCC) [7], when the main grid fails, MG transfer from grid-connected mode and works independently in island mode.

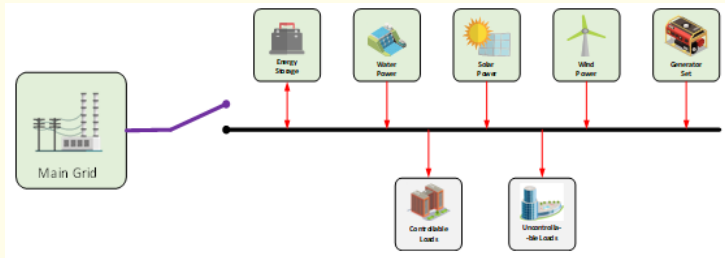

Figure 2: MG operation modes.

Solar Microgrids (SMG): is a type of MG, combined from a solar energy source and low-cost natural gas or diesel generators installed central location to feed different loads [8], as shown in Figure 3, SMG also can work in grid connected or island mode.

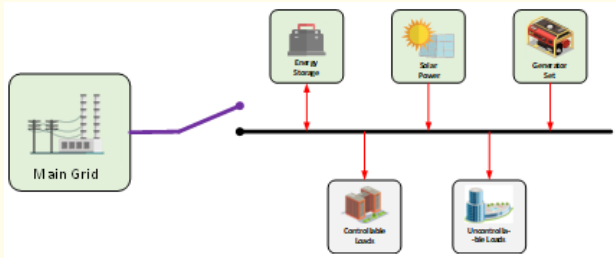

Figure 3: Solar Microgrid.

Despite all the benefits of the MGs, but it still has a challenge, especially when the main grid fails, MG operates in island mode, that means that MG will operate in the one direction which is transmitting electrical power from DGs to the electrical loads, in other words the loads of the MG can be fed from the DGs of MG only. Due to changeability and uncontrollability of DGs output power like PV generator, Wind generator, etc. [9], there are scenarios like power imbalance, where the generated power is less than the consumed power [10], which can lead to a rapid drop in operating frequency ranges of the MG power system and MG power system outage also can happen [11].

Power system outages can be categorized into three different phenomena, according to the its duration and effects [12]:

1. A transient fault is a loss of power produced by the power supply to the consumer.
2. A brownout is an intentional or unintentional drop in voltage in an electrical power supply system, the voltage is typically reduced by at least 10 to 25 percent [13].
3. A blackout is the total cut of power to an area for the long or short duration and is the most common form of the power system outage that can occur. Blackouts are difficult to recover from quickly [14].

For Avoiding these mentioned problems, and keep the MG frequency in acceptance range, there is a need to keep the balance between the produced power of DG and the consumed power by the MG loads by adjusting or controlling the load demand rather than the DGs output power [15]. The load shedding strategy is a way to distribute the load demand by removing some of the MG controllable loads from the system systematically until the MG can be maintained within satisfactory operating limits utilizing the local DG [16].

Solar power forecasting is the process of predicting the produced power of solar system on various time [17], it can be classified into three types according to forecasting horizon, Now casting (forecasting 3–4 hours ahead), Short-term forecasting (up to seven days ahead), and Long-term forecasting (weeks, months, years). Now casting refers to the prediction of power generation capacity over time horizons of tens to hundreds of minutes ahead of time with up to 90% predictability [18]. Which can be done by determining the cloud behavior and solar intensity using Sky images in proximity to the photovoltaic panels are used [19]. Recently, there is many soler forecasting tools is developed, that can predict the daily produced power of the solar systems up to a 90 per cent probability, like solar prediction tool which is integrated into the University of New South Wales-developed APVI Live Solar Map [20].

Material and Methods

Experimental Procedures

The proposed SMG in this paper is consisting of Solar Power system connected in parallel with Diesel Generator, that SMG can works in the two operation modes, grid-connected mode and stand-alone mode, During the grid-connected mode, the SMG can effectively stabilize and control the interruptions of solar power and reduce the impact on the loads; When the main grid fails or other situation happened that force the proposed SMG to separate from the main grid and works in stand-alone mode, in that time, when the load

demand exceeds the produced power, the proposed ILSF Strategy will be enabled.

The proposed system (ILSF) combined with three inputs which is: SMG Forecasting Data (SMG-FD), Load Consumption, and Main Grid Availability and one output: Percentage of Load Shedding (PLS) as shown in Figure 4.

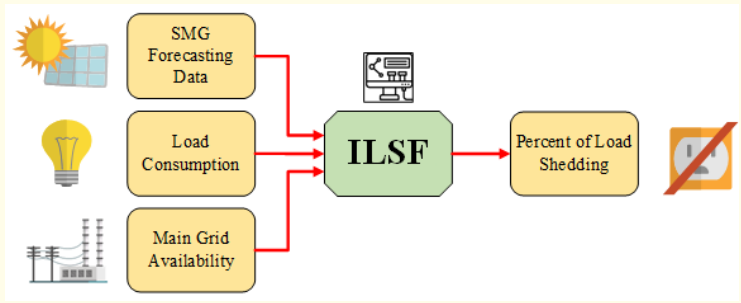

Figure 4: The proposed ILSF system.

SMG-FD is the prediction data of power capacity that can be generated by the DGs of SMG over the time, which is Solar System and Disel Generator, Disel Generator is used to keep some of critical loads on, regardless of SMG operation mode.

Behavior of a fuzzy system can be described by using a set of IF-THEN rules between inputs and outputs that may be expressed in natural language without using complex mathematical equations [21], ILSF take FLC as a controller for the main system, take the SMG-FD and Load Consumption as FLC inputs and take PLS as FLC output, as shown in Figure 5 below:

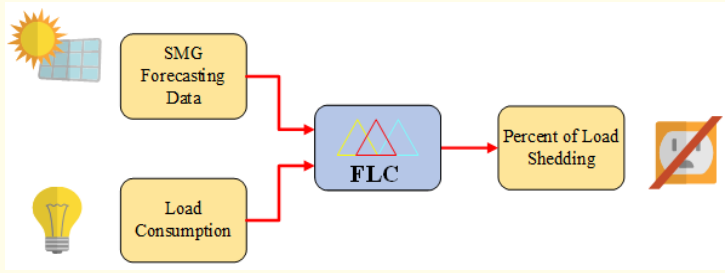

Figure 5: The proposed FLC system.

Firstly, the ILSF system will read the state of Main Grid Availability which is logical data (0, 1). If the state is 0, that mean MainGrid is unavailable, the SMG will work in stand-alone mode, PLS will be determined by FLC according to the reading of SMG-FD and Load Consumption Data. As a determined PLS value, ILSF system will start the shedding process on the SMG loads according to the priority of these loads by using Shedding Function, in other hand, if state is 1, that mean SMG is working in Grid-Connected mode and no need for shedding loads, The flow chart of ILSF is depicted in Figure 6.

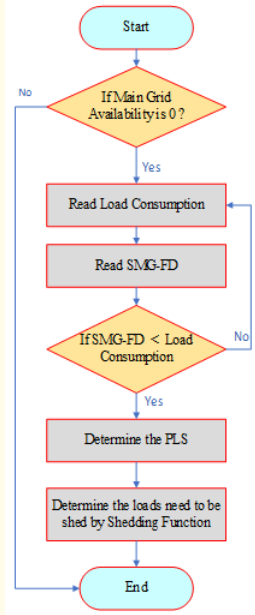

Figure 6: Flow chart of ILSF.

The provided system prioritizes the loads of SMG based on certain rules. To achieve this, the residential loads of SMG are classified into first priority loads (1-P), second priority loads (2-P), and third priority loads (3-P), as shown in Figure7, the 1-P loads are given highest priority and therefore are allowed to operate at their scheduled time while the 2-P loads and 3-P loads are of less priority, hence can be shed and shifted to a time where there is enough electric power generation from the PV arrays or when the SMG is transferred to the grid-connected mode. The loads arrangement in every group is done according to SMG working nature.

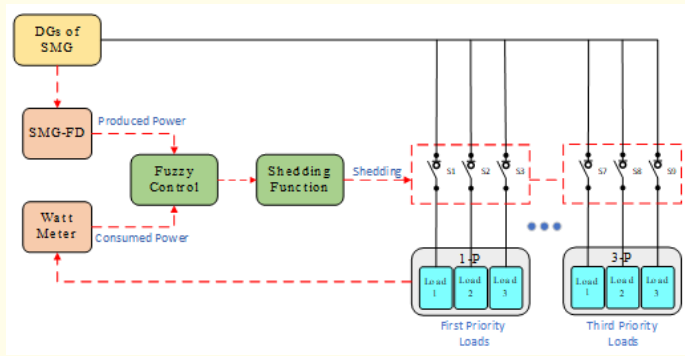

Figure 7: One-Line diagram of SMG system.

The Shedding Function will start shedding the loads according to PLS, one by one, starting with checking the 3-P loads group, is there on-load in that group or not, if yes, the function will shed the first on-load, after that, there is a new Load consumption and new PLS will be determined by FLC, the shedding function will check, if the new PLS is less than or equal to 0, according to that, the function will determine, stop shedding or continue; If the PLS is still higher than 0 , and there no on-loads in 3-P loads group, the system will

move to check the 2-P loads group and repeat the steps, if there no onloads in 2-P loads, and the system have a very low SMG-FD values (diesel generator is off and solar power is very low), Shedding Function will move to check the 1-P loads as shown in Figure 8 below.

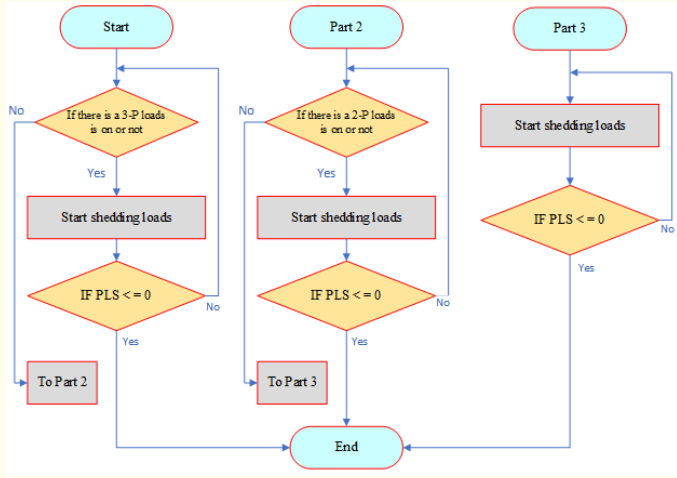

Figure 8: Flow-chart of Shedding Function.

Results and Discussion

The proposed control system ILSF is implemented using MTLAB 2021- SIMULINK as shown in Figure 9 below:

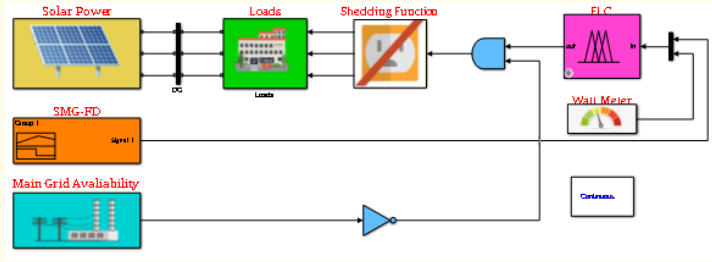

Figure 9: SMG system implemented in SIMULINK.

The proposed SMG in the simulation has a solar power system with power production capacity can reach to 60kW at Sun peak hours, connected in parallel with 30kVA Disel Generator, working in two operation modes, to cover different electrical loads demand have a total power consumption 95KW/h, and classified in different groups according to its priority (1-P, 2-P, 3-P) as illustrated in Figure 10 below:

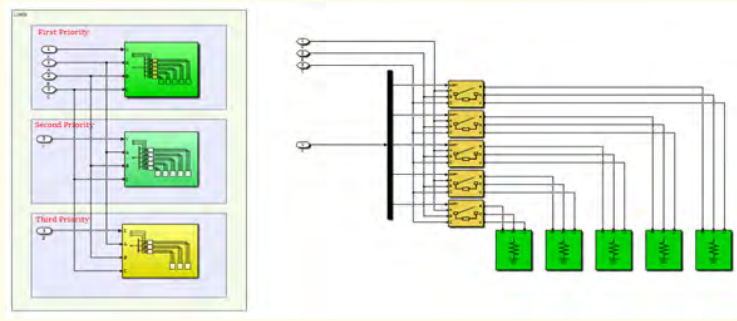

Figure 10: Proposed loads of SMG in SIMULINK.

The proposed FLC is implemented using MATLAB 2021-Fuzzy Tool as shown in Figure 11, the FLC is Mamdani type, has two inputs, which is SPND and Load _ Consumption and one output: PLS.

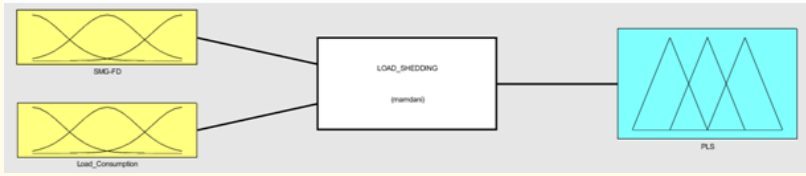

Figure 11: FLC in MATLAB program.

Approximately 24 sets of IF–THEN rules governing input and output variables cover all situations that can be faced all the day. The 3D fuzzy surface is depicted by the FLC rules in MATLAB. As shown the Figure12 below:

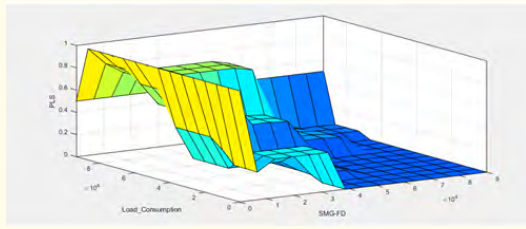

Figure 12: Proposed FLC surface.

The output surfaces presented a dimensional curve that represents the mapping of SMG-FD (W), Load Consumption (W) and PLS. The input and output variables in Figure 13, depicts details influenced by the inputs and output membership functions, in order to view the entire surface of the fuzzy inference system.

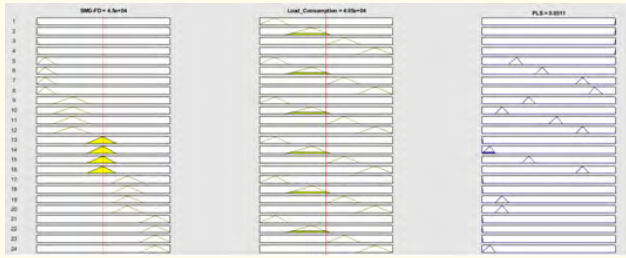

Figure 13: Inputs and outputs results of FLC.

Case Study

The provided case study is given by assuming different SMG-FD and Load demand values over 24 hours in the provided SMG, as shown in Figure 14- (A, B):

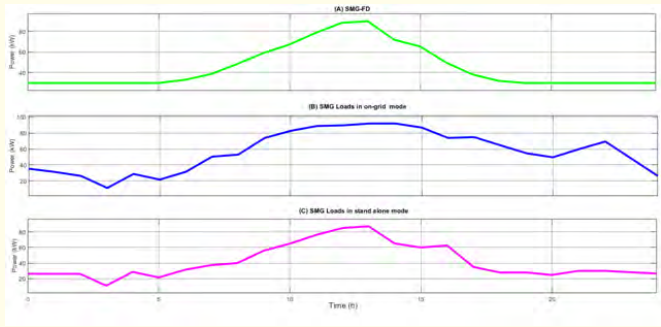

Figure 14: (A): SMG-FD, (B): SMG load values in on-grid mode, (C): SMG loads values in stand-alone mode.

The assumed SMG-FD values is between 30kW as a minimum value of DGs (Solar power = 0, Disel Generator Power = 30kW) generated power, especially in the night hours and 90kW as a maximum value in Sun peak hours as shown in Figure 14-(A), when the Main Grid is available and SMG works in grid-connected mode, SMG loads work freely regardless of SMG-FD as shown in Figure 14-(B).

As shown in Figure 14-(C), when the SMG works in the off-grid mode, the results prove that ILSF provided the load balance between the loads demand and the generated power of DGs by achieving load shedding strategy based on FLC, taking in account the priority of loads.

Conclusion

Load management is the main key of Microgrid system, and there is a lot of strategies for applying it. The preferred strategy ILSF aims to keep a balance between the production capacity of microgrid resources and the consumption capacity load in the same time, especially when the MG works in island mode, to keep the MG frequency in acceptable ranges, by shedding some loads depending on its priority, which is defined by the company or the users depending on the nature of using these loads.

FLC can cover a wider range of operating conditions by editing rules between inputs and output without mathematical equations, due to using FLC, ILSF is simple, flexible and allow modifications.

References

1. Wu J, Yan J, Jia H, Hatziargyriou N, Djilali N and Sun H. "Integrated energy systems''. Appl Energy (2016).
2. Global Energy Review (2020).
3. Zia MF, Elbouchikhi E and Benbouzid M. "Microgrids Energy Management Systems: A critical review on methods, solutions, and prospects''. Applied Energy 222 (2018): 1033-1055.
4. Al-Saadi M, Al-Greer M and Short M. "Strategies for controlling microgrid networks with Energy Storage Systems: A Review''. Energies 14.21 (2021).
5. Garg VK and Sharma S. "Overview on Microgrid System". Fifth International Conference on Parallel, Distributed and Grid Computing (PDGC), IEEE, Solan, India (2018): 694-699.
6. Gupta N. "Generation scheduling at PCC in grid connected microgrid". International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014), IEEE, Jaipur, India (2014): 1-5.
7. What is a Microgrid (2022).
8. Sloar Microgrids (2022).
9. Gharehpetian GB and Mousavi M. "Distributed generation systems: Design, operation and grid integration''. Butterworth-Heinemann, an imprint of Elsevier (2017).
10. Wang C, YuH, Chai L, Liu H and Zhu B. "Emergency Load Shedding Strategy for Microgrids Based on Dueling Deep Q-Learning". IEEE Access 9 (2021): 19707-19715.
11. LiuS, LiuL, YangN, MaoD, ZhangL, Cheng J, XueT, LiuL, Yan G, Qiu L, Chen X, Zhang M and ShiR. "CA data-driven approach for online dynamic security assessment with spatial-temporal dynamic visualization using random bits forest''. Int. J. Electr. Power Energy Syst 124 (2021): 106316.
12. Dobson I, Chen J, Thorp J, Carreras B and Newman D. "Examining Criticality of Blackouts in Power System Models with Cascading Events". 35th Annual Hawaii International Conference on System Sciences (HICSS'02). IEEE, Washington, USA (2002).
13. Power brownout (2022).
14. Powerblockout (2022).
15. Choi Y, Lim Y and Kim H-M. "Optimal Load Shedding for Maximizing Satisfaction in an Islanded Microgrid''. Energies 10.1 (2017).
16. Ilyushin PV and Filippov SP. "Under-Frequency Load Shedding Strategies for Power Districts with Distributed Generation". International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), IEEE, Sochi, Russian (2019): 1-5.
17. David P Larson, Lukas Nonnenmacher and Carlos FM. "Coimbra, Day-ahead forecasting of solar power output from photovoltaic plants in the American South westmimimi". Renewable Energy 91 (2016): 11-20.
18. New APVI solar tool shows daily, time-based forecast for each state (2022).
19. Haputhanthri D, Silva D, Sierla S, Alahakoon D, Nawaratne R, Jennings A and Vyatkin V. "Solar Irradiance Nowcasting for Virtual Power Plants Using Multimodal Long Short-Term Memory Networks". Frontiers in Energy Research 9 (2021): 1-13.
20. New APVI solar tool shows daily, time-based forecast for each state (2022).
21. Lee CC. "Fuzzy logic in control systems: fuzzy logic controller. II". IEEE Transactions on Systems, Man, and Cybernetics 20.2 (1990): 419-435.

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