Microgrid Load Management Control Application

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***Abstract* — This paper presents load management strategy for a microgrid (MG) comprising of wind, PV, micro-hydro, diesel, energy storage system to increase penetration from renewable energy resources (RERs). The main objective of this work is to solve power shortage problem in MG by increasing the penetration from RERs. The results presented in the paper show that microgrid is able to maintain balance between the generation and demand with significant contribution form RERs. Microgrid can also supply meet additional current or future load requirement if microgrid site is rich with the availability of natural resources and avoid load shedding and blackout problems.**

***Index Terms* — Load management technique, microgrid system, critical and future loads, RERs.**

I. Introduction

Electric power has shaped and contributed to the progress and advances of humankind over the past century. Power should be available to the customer upon demand [1], [2]. The power companies strive to keep the reserve capacity to meet the sudden demand to a minimum. Load management techniques help the power companies to reshape the electric utility load curve and to reduce the peak demand [3]-[5]. The United States Government has filed lawsuits against 32 electrical utility plants charging the release of massive amounts of air pollutants throughout the Midwest and East coast [6], [7]. A microgrid (MG) is a group of interconnected loads and distributed energy resources (DER) which clearly defines electrical boundaries that acts as a single controllable entity with respect to the grid. The small capacity hydro-units, biogas, wind, photovoltaic (PV) systems are the various energy resources in MG. The MG assists in reducing the line losses, network congestion, and line costs by higher energy efficiency [8]. Incorrect operation of protective systems, especially distance relays have been the main cause of recently blackouts [9], [10]. Over the last decades, in the world several severe blackouts have happened and these actions cause the economy loss and social impact [11]. Generally, the MG operates in two modes which are islanded and grid-connected. In grid-connected mode, the MG is interconnected with a power system and can exchange its power with the main grid. There is in islanded mode, the MG operates with its only energy resources and no interconnection with the grid system and parameters such as frequency, voltage control and instability are main issues [12], [13]. Others aspects for islanded mode are the inefficient design or lack of Under Frequency Load Shedding system (UFLS) [14], lack of under voltage load shedding system, and inefficient vegetation management strategies. In addition, smart MGs face some policy and regulatory barriers here that are being challenged as the reliability, quality and environmental benefits. The consequences of such difficulties make their offer become clearer [15]. MGs may be very good in conception, depending on market segment, size and location. Some of existing types of MGs are listed and well known as Remote MG, Customer MG, Utility and Virtual MG. Load shedding is the last expected protection possibility against cascading outages [16]. Besides the introduction, this paper is organised in three sections. The second section presents the problem formulation of the typical MG system, where the MG system is presented and described with an appropriated structure. The third section explains the simulation results of the applied mathematical modelling of the power distribution system and the fourth section presents the conclusion of the completed work.

II. Problem Formulation

This section is characterised by three sub-sections which are the system description of the MG, the multi-objective function of the problem and the constraints equations of the MG power system.

A. System description

The typical MG structure used in this work is presented in Figure 1. The system is composed of two main parts, namely the supply and the demand sides. The supply side is characterised by five sources of energy such as diesel generator (DG) unit, micro hydropower (MH), wind turbine generation (WTG), photovoltaic (PV) and battery bank systems which one operate under normal and abnormal conditions of the MG system. The demand side is characterised by active loads (P_{L1}), (P_{L2}), (P_{L3}), (P_{L4}) and future loads (P_{L5}), (P_{L6}). The micro hydropower system comes into force, to balance the system, in case of additional load and to increase the total power produced by the RERs in MG system.

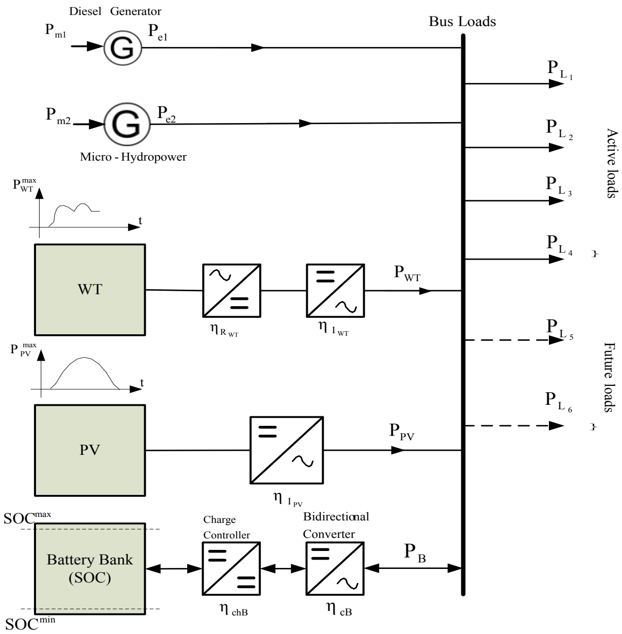

Figure 1. Typical model of microgrid system

Additionally, the rating of parameters of the others data to be applied into the simulation of the hybrid system are given in Table 1 [17].

Table 1: Rating of parameters of the data of MG system

No	***Parameters***	***Ratings***	***Priority***
1	DG output power	3 kW, ηDGg=0.8	High
2	Diesel fuel price	1.1$/litre	High
3	DG parameters	a = 0.246, b = 0.0815, c = 0.4333	
4	Sampling time and priority factors	1 hour ; w1 = 0.25 and w2 = 0.75	High
5	Nominal capacity of the Battery Maximum SOC Minimum SOC Discharging efficiency Charging efficiency	2 kWh or 0.5kW or 85Ah 95% 40% 95% 80%	High
6	Accepted MG system frequency Accepted MG system voltage	(50 ±1.5) Hz (1± 0.05) pu	High
7	RERs Micro-hydropower WTG system PV system unit	4 kW, ηHg1= 0.9 2 kW, ηWTg = 0.85 2 kWmax, ηPVg = 20%	High
8	Maximum load capacities: active loads: (PL1), ..,(PL4) and future loads (PL5), (PL6)	1 kW, 1 kW, 1 kW, 1 kW and 2.8kW, 1.8 kW	High

B. Multi-objective function

The application of the DG will preferably be running only for a short period in such a way the RERs systems have been prioritized at the standard level to keep the operating cost of the system lower, as long as the MG is operating. The main purpose of this study is to reduce the fuel cost of the DG and to maximize the output power from RERs with the objective to satisfy the load management problems in MG.

The first objective function is given by expression (1) as follows:

$$\text{Obj}_1 = \min \text{C}_\text{f} \sum_{i=1}^{N_s} \text{w}_1 \times [aP_{DG}^2(i) + bP_{DG}(i) + c], \begin{Bmatrix} 1 \le i \le N_s \\ w_1 = 0.25 \end{Bmatrix} \quad (1)$$

Where, where C_f is the cost of the fuel used to run the DG; a, b and c are factors applied to the fuel properties; P_{DG} is the output power from DG unit to the hybrid system; i is the time horizon and N_s is the number of time periods considered for the optimization study of MG system, w_1 is the priority factor taken into account for the use of fuel applied to the DG considered into the MG system.

To maximize the RER output power, the second objective function is characterised by expression (2) as:

$$\text{Obj}_2 = -\min \sum_{i=1}^{N_s} w_2 \times [P_{RER}(i)], \begin{Bmatrix} 1 \le i \le N_s \\ w_2 = 0.75 \end{Bmatrix} \quad (2)$$

Where, where w_2 is the priority factor taken into account for the use the RERs considered into the MG system, P_{RER} is the output power from RER systems.

The combination of both (1) and (2), will solve the load management issues in MG and the multi-objective function is considered as the sum of both equations (1) and (2) given by (3):

$$\text{Obj}_1 + \text{Obj}_2 = \min \text{C}_\text{f} \sum_{i=1}^{N_s} \text{w}_1 \times [aP_{DG}^2(i) + bP_{DG}(i) + c] - \min[\sum_{i=1}^{N_s} w_2 \times P_{RER}(i)] \quad (3)$$

C. Microgrid constraints

The MG constraints are characterised by power balance, frequency equations of the system. The power balance of MG is given in discrete form by expression (4) as:

$$\begin{cases} P_{DG}(k) \ge \sum_{l=1}^{3} P_{Lj}(k) + P_{L5,6}(k) \\ \sum_{j=1}^{m} P_{MH}(k) + P_{WT}(k) + P_{PV}(k) \pm P_B(k) \ge \sum_{l=1}^{3} P_{Lj}(k) + P_{L5,6}(k) \end{cases}, \begin{Bmatrix} 1 \le k \le N_s \\ l = 1,...,6 \\ \text{m} = 1 \end{Bmatrix} \quad (4)$$

where $P_{Lj}(k)$ is the index of active loads; $P_{L5,6}(k)$ is the index of future load in the MG system, $P_{DG}(k)$ is the power from the diesel generator systems $P_{PV}(k)$ and $P_{WT}(k)$ are the power from the PV and WTG systems, $P_B(k)$ is the power delivered by the battery bank system (BBS).

The dynamic in time and discrete domain of the DG, the micro hydropower and the battery systems are given by the system of equations (5) as follow:

$$\begin{cases} P_{aDG,MH}(t) = M\dfrac{d\omega t}{dt} = P_{mDG,MH}(t) - P_{eDG,MH}(t) \\ \omega_d(k) = \omega(0) + \dfrac{\Delta t}{M_{DG,MH}}[\sum_{\tau=1}^{k} P_{mDG,MH}(\tau) - \sum_{\tau=1}^{k} P_{eDG,MH}(\tau) \\ \omega_d^{\min}(k) \le \omega_d(k) \le \omega_d^{\max}(k) \\ SOC(k) = SOC(0) - \dfrac{\Delta t}{C_n}\sum_{\tau=1}^{k} P_B(\tau) \\ SOC^{\min} \le SOC(k) \le SOC^{\max} \end{cases} \quad (5)$$

where $P_{aDG,MH}$ (k) is the accelerated power of DG and micro hydropower; $P_{mDG,MH}(k)$ is the mechanical power of DG and micro hydropower; $P_{eDG,MH}$ (k) is the electrical power of DG and micro hydropower; SOC (k) is the state of charge of the battery system, $P_{DG}(k)$ is the power from the diesel generator system, $M_{DG,MH}$ is the moment of inertia in $MJ/MJ/rad/s$, SOC^{min} and SOC^{max} are the upper and lower limits of the SOC, $\omega_d{}^{\max}$ and $\omega_d{}^{\max}$ are upper and lower limits of angular speed $\omega_d(k)$, Δt is the variation of time.

The boundary constraints of the considered variable parameters into the MG system are presented by the system of equations as follows:

$$\begin{cases} P_{DG}^{\min}(k) \le P_{DG}(k) \le P_{DG}^{\max}(k) \\ P_{MH}^{\min}(k) \le P_{MH}(k) \le P_{MH}^{\max}(k) \\ P_{WT}^{\min}(k) \le P_{WT}(k) \le P_{WT}^{\max}(k), \left(1 \le k \le N_s\right) \\ P_{PV}^{\min}(k) \le P_{PV}(k) \le P_{WT}^{\max}(k) \\ P_{B}^{\min}(k) \le P_{B}(k) \le P_{B}^{\max}(k) \end{cases} \quad (6)$$

III. SIMULATION AND RESULTS OF MICROGRID

To verify the performance of the proposed control system applied in this study, the availability of accurate load data is an important factor. Moreover, the design of RERs must be done according to the predefined objective, which means that it is necessary to meet the load capacities requirements.

A. Algorithm applied for this case study

The fmincon function of MATLAB R2015 Optimisation Toolbox is implemented to solve all elements of this problem. The equation can be solved by this function expressed as follows:

$$\min f(X) \quad (7)$$

Subject to

$$\begin{cases} \mathrm{AX} \le \mathrm{b}\,(\text{linear inequality constraint}), \\ \mathrm{A_{eq}X} = \mathrm{b_{eq}}\,(\text{linear equality constraint}), \\ \mathrm{C(X)} \le 0\,(\text{nonlinear inequality constraint}), \\ \mathrm{C_{eq}}(X) \le 0\,(\text{nonlinear equality constraint}), \\ \mathrm{L_b} \le \mathrm{X} \le \mathrm{U_b}\,(\text{lower and upper bounds}). \end{cases} \quad (8)$$

The fmincon function defined by equations (7) and (8) is more efficient to be applied to typical model of MG system with regards in taking into account all necessary parameters as per described Table 1. For the optimal control equation, the vector X contains the feeders' speed for all sampling intervals. The linear inequality constraints are integrated into A and b. The lower and upper boundary constraints (5) and (6) are included into L_b and U_b.

B. Variation of wind, irradiation and load capacity

The variation for a typical household for wind, PV output power due to irradiation and load capacity have been collected in summer period [18]. These graphs have been plotted with the implementation of Matlab programming tool as given in Figures 2 - 4 as [18]:

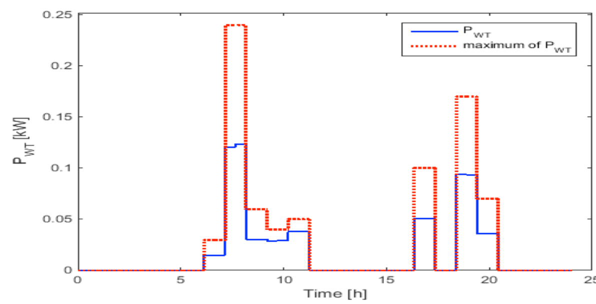

Figure 2. Variation of output power from WTG

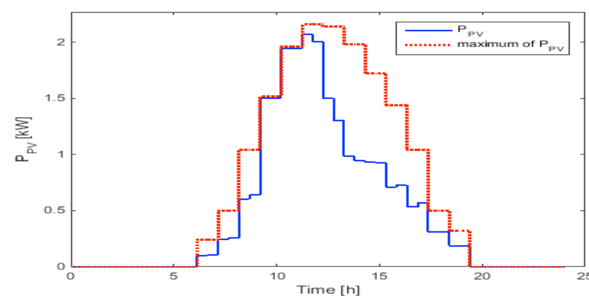

Figure 3. Output power from PV

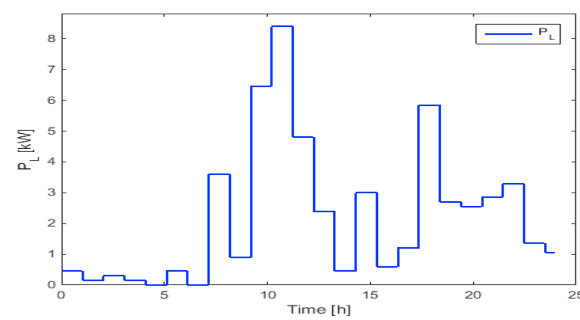

Figure 4. Load profile of the Household

The study of the typical MG system is principally based on the consumption of the household system. The maximisation of power from RER units is coming into force to the power distribution system with the objective to reduce unnecessarily operating delays due to power shortage caused by supply side of MG. The consequences of power shortage are the main factors reducing the balance performance of the MG. From the graphs presented earlier by Figures 2 - 4, load management control will be made with the objective to keep supplied the household permanently with energy from the generation side of MG power system. Load management will be completed with the application of RERs and the focus will be on the variation of power balance variable of MG. This variable will confirm either the action of load management has been achieved or not.

C. Load management with total load capacity connected

At this stage, only the DG is supplying the demand side of the MG system. As results, the Figures 5-7 show that the DG is facing a serious problem and the power balance of the distribution system is not good, the solution to be applied for this case, is to shed all future connected loads. As impact, the system is balanced and everything has become too normal.

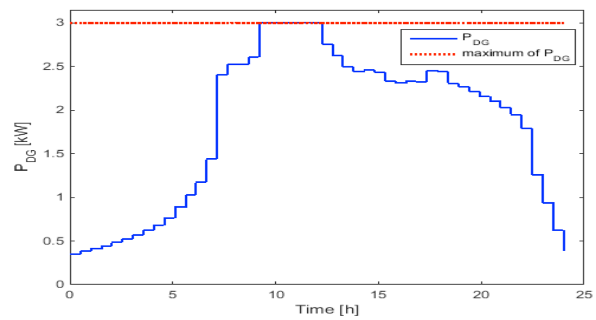

Figure 5. Power from the DG supplying the Household

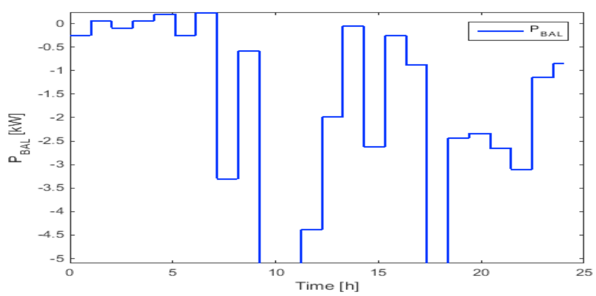

Figure 6. Power balance for the MG system

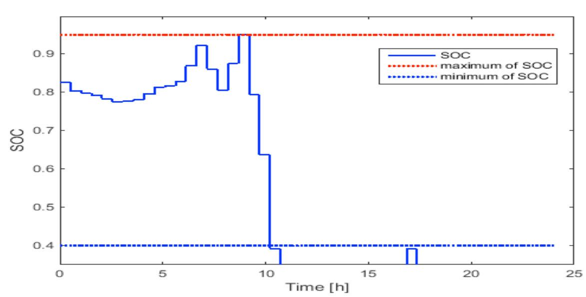

Figure 7. Variation of SOC for the Household

The implication of RERs system has been applied to the MG configuration, full load capacity has been considered and Figures 8 – 11 have proven that load management of the MG system has been completed by RERs and the power balance of the distribution system is in acceptable limits according to the standards. Additionally, no need of shedding all future loads to be connected into the household. The solution for this case is no need of action to reduce the load on demand side of MG system, especially the interruption of an electricity supply to avoid excessive load on the generating systems. Additionally, no deliberate shutdown of electric power in a part or parts of a power-distribution system, generally with the contribution of RERs, there is no need to prevent the failure of the entire system when the demand strains the capacity of the system. There is no worry to think about origin of load-shedding as the demand side management (DSM) problem has been completed with additional renewable resources.

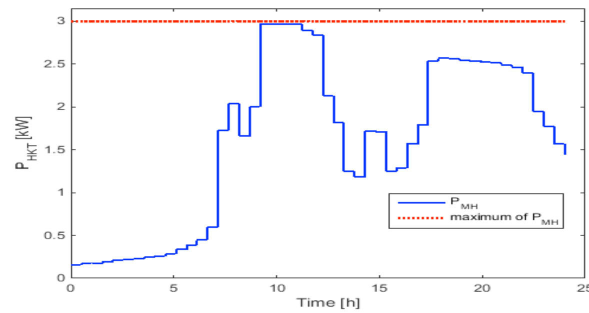

Figure 8. Power from the MH supplying the Household

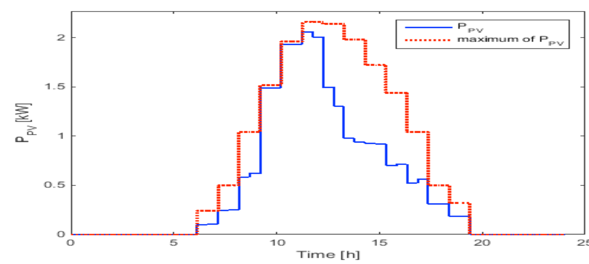

Figure 9. Power from PV supplying the Household

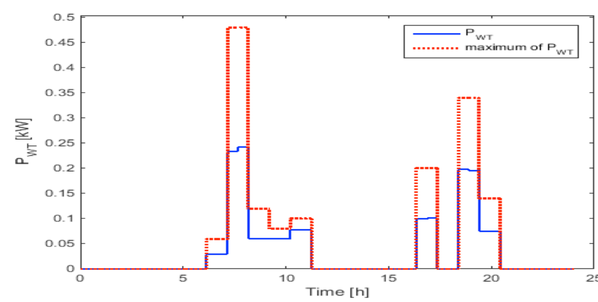

Figure 10. Power from the WTG supplying the Household

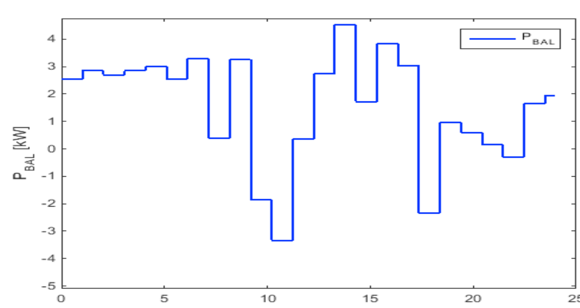

Figure 11. Power balance for the Household

As this can be seen from the comparison between Figures 6 and 11, load management of the MG system is secured with the application of RERs as the power balance seems to be positive as shown in Figure 11.

Additionally for this study, the results have proven that load management, also known as DSM, is the process of balancing the supply of electricity on the network with the electrical load by adjusting or controlling the load rather than the supply side output. Figure 11 proves that load management allows utilities to reduce demand for electricity during peak usage times, which can, in turn, reduce costs by eliminating the need for peaking power from DG. In addition, Figures 5 and 7 show that some peaking source of power can take more than an hour to bring on-line which makes load management even more critical should the DG and battery output power go off-line unexpectedly according to the high demand of the household. According to Figure 11, it is confirmed that load management performance can also help reduce harmful emissions, since peaking plants or backup generator is often dirtier and less efficient than base load power plants.

IV. CONCLUSION

This paper has discussed the necessity of the use of load management solution into the MG power distribution system. The main objective of such application is to make sure that the supply side of MG system is able to supply future additional load with the impact of RER systems. RERs are environmental friendly and need to be considered for the development in rural community. As recommendation, it is important to take the opportunity of RERs for the assurance of the future of manufacturing companies and industries.

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