Assessment of power flow constraints impact on the energy management system of multi-microgrid based distribution network

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Load growth, high penetration of distributed generators (DG) and energy storage systems (ESSs) have caused different challenges for the distribution networks (DNs) such as congestion in their lines. This paper assesses the impact of congestion on the operational cost of the multi microgrid (MMG) based DN firstly. Then, a security constrained energy management system (SC-EMS) for the MMG system is proposed by considering the effect of the network's load flow constraints on the scheduling of that. Obviously, adding extra constraints to the optimization problem of the MMG system leads to increment in the operational cost. In order to resolve this problem, tie lines between MGs are modelled. In fact, in the proposed model, MGs can trade energy not only with the DN, but also with other MGs. Moreover, it is evaluated that considering the MGs as an integrated unit decreases the overall operational costs. Simulations on a modified IEEE 33-bus test system with multiple MGs are performed in GAMS environment. As expected, the gained results demonstrate the increment in the operational costs of the DN and the MGs when the contingencies occur in the network's lines. On the other hand, taking the tie lines into account as a recommended solution leads to a decrement in the operational cost of the MMG system.

keywords: *Energy management, security constraint, multi microgrid based distribution network, power flow constraints*

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NOMENCLATURE

i, j	Index for bus.
l	Index for branch.
t	Index for time.
$diesel$	superscript for diesel DG.
$renew$	superscript for renewable DG.
min	superscript for min amount of the variable.
max	superscript for max amount of the variable
$ahead$	superscript for expressing next variable.
$back$	superscript for expressing previous variable.
$Ramp^{up,down}$	Ramp up/down coefficient of diesel DG (MW/h).
$A_{1,2,3}$	Cost func. coefficient of diesel DG.
$P^{max}_{B,ch}$	max charging power of battery (MW).
$P^{max}_{B,dis}$	max discharging power of battery (MW).
$P^{min}_{B,ch}$	min charging power of battery (MW).
$P^{min}_{B,dis}$	min discharging power of battery (MW).
$P^{up,down}_{B,ch}$	Ramp up and down power for charging state.
$P^{up,down}_{B,dis}$	Ramp up and down power for discharging state.
R_{line}	branch resistance (Ω).
X_{line}	branch reactance (Ω).
V^{max}	Max voltage magnitude in each node (kV).
V^{min}	Min voltage magnitude in each node (kV).
I^{max}_{line}	max allowable line current (A).

P_{DG}^{prenew}	Forecasted renewable unit active power (MW).
P_{load}^{demand}	Active consumed power of each node (MW).
Q_{load}^{demand}	Reactive consumed power of each node ($MVaR$).
$\eta^{ch,dis}$	efficiency rate of charging/discharging %.
$\beta_{i,j,l}$	Indicates that l line exists between nodes i, j or not.
$price_{buy}^{DN}$	price of buying power from DN ($\$/MWh$).
$price_{sell}^{DN}$	price of selling power to DN ($\$/MWh$).
$price^{curt}$	Price of curtailed load ($\$/MWh$).
$price^{up}$	Price of buying (selling) from (to) upstream network ($\$/MWh$).
i_{back}	Set of lines which are connected to node i.
i_{ahead}	Set of lines which are extracted from node i.
χ	Set of MGs.
P_{DG}	Generated power of diesel unit (MW).
$Cost_{DG}$	cost function of DG unit ($).
C_{stup}	start-up cost of DG unit ($).
C_{stup}	Start up cost of DG unit (MW/h).
$P_{B,ch}$	charging power of each ESS unit (MW).
$P_{B,dis}$	Discharging power of each ESS unit (MW).
SoC	State of charge amount of battery.
V	Voltage magnitude of each node (kV).
η_i^{χ}	bought power of entity χ from i (MW)
I_{line}	branch current (A).
P_{line}	Active power passing from each line (MW).
Q_{line}	Reactive power passing from each line ($MVaR$).
P_{load}^{curt}	curtailed active load of each node (MW).
Q_{load}^{curt}	curtailed reactive load of each node ($MVaR$).
U	Binary variable Indicates status of charging or discharging.

1. INTRODUCTION

Rapid penetration of distributed generators (DGs), increment in energy demand, improving the reliability and the security of electrical systems and environmental concerns, have caused that the electrical power systems to face new challenges [1, 2]. Microgrids (MGs) are one possible solution to overcome the mentioned drawbacks, which have crucial and undeniable part in transforming conventional power systems to modern and smart ones. An MG is combination of DGs, Energy Strage Systems (ESSs), loads and interfacing converters with an energy management system (EMS) to control the power production and consumption. The EMS is responsible for determining the generation set points for the dispatchable DGs, maximum power point tracking for renewable based DGs, managing controllable loads, etc. [3]. MGs have two modes of operation: a) Grid-Connected Mode, b) Islanded Mode. They work in the first mode to maximize the benefit of the MG and the second mode of operation is preferable to enhance the reliability and security in emergency events [4, 5].

EMS has gathered the attention of so many researchers. Zhang *et al* [6] have proposed a distributed economic dispatch for an MG in grid connected mode of operation, with high penetration of renewable based DGs. In ref [7] authors have proposed a stochastic EMS for an MG with sporadic renewable energy resources and electric vehicles (EVs) with the aim of minimizing the operation costs and power losses. Falahi *et al* have presented a dynamic control strategy, which has a model predictive control-based structure, as an EMS for regulating the active and reactive power in an MG, in [8]. In [9], an EMS based on a rolling horizon algorithm for an MG by considering forecasting models and solving the dispatching problem as a mixed integer program, have been proposed. Authors in [10], have proposed the mixed integer linear programming (MILP) approach for energy management of the MG in the grid connected mode. In [11], authors have stochastically formulated the energy management problem in an MG, considering the uncertainties in both demand and supply sides. In the mentioned reference, to solve the stochastic energy management problem, the problem is transmuted to a standard convex quadratic programming, by means of machine-learning approaches. Kanchev *et al* [12] have proposed a determinist EMS for an MG, including PV generation units, ESSs and a gas microturbine with the a central energy management of the MG and a local power management of the customers. A double-layer EMS for an MG has been proposed in [13] in which one layer is known as the schedule layer which aims to obtain an economic operation plan according to the forecasted data, and the other layer as a dispatch layer, determines the reference power of the DG outputs according to the real-time data. Marzband *et al* [14], have used a meta-heuristic approach named multiperiod artificial bee colony (MABC) optimization algorithm, for economic dispatch in an islanded MG considering generation, storage, and demand response programs. Authors in [15] have proposed MILP model for energy management of an MG considering security constraints and unexpected outages of the main grid. Likewise, authors in [16], have used another bio-inspired algorithm to solve the combined problem of network reconfiguration and EMS which results in more effective incorporation of the MG into the network. Authors in [17] have recommended EMS for MG by considering the hydrogen system beside other renewable resources. Authors in [18] have proposed the multi objective scheduling for the MGs which is composed of heat and power demands. Likewise, in ref [19], robust optimization has been proposed for such MGs.

In all of the above references, only one MG have been considered. However, with growing number of the MGs, the distribution network (DN) might contain multiple MGs. Connecting various MGs to the DN could ease the operation of such systems [20] , which is named as Multi Microgrid (MMG) system. In an MMG system, each MG and the distribution network operator (DNO) can participate as independent units. However, with a coordinated EMS, both the DNO and MG owners could decrease their operational costs and the costumers could profit from a more reliable and secure electrical power [3]. Thus, studying MMG systems has been of interest, recently. Authors have considered the two stage energy management for the networked MGs in [21] so as to increase the accuracy of the control under the situation of high uncertainty in the system. Authors in [3], propose a decentralized bi-level algorithm as an EMS for the coordinated operation of MMG system. A hierarchical optimization algorithm is proposed in [22], which aimed for coordinated operations of MMGs and DNO without considering the islanded operation of the MGs and the uncertainties of renewable energy based DGs and load consumption. In order to reduce the overall cost of the network, the cooperative working of the MGs has been proposed in [23]. Also, the distributed approach is selected for solving the problem in this paper. Multiagent systems (MASs) are used as the EMS of the MMG systems in [24], which leads to participation of different entities in the restructured electrical environment. Authors in [25] have applied the bi-level programming as the EMS of an MMG system. Wang *et al.* [26] proposed a novel control strategy for coordinated operation of MMG system by considering of the problem as a stochastic bi-level problem where the DNO is in the upper level and MGs are in the lower level. Likewise, Tianguang Lv and Qian Ai [27] proposed a novel EMS for a MMG system formulating the energy management problem as a bi-level multi-objective optimization problem with the distribution network in the upper level and MG in the lower level. Wu and Guan have proposed a decentralized Markov decision process for modelling the optimal control problem of MMG system and minimizing the operation costs of MGs, in [28]. Authors in [29] have considered the impact of contingency on the energy management of the multi microgrids. Hierarchical based control strategy has been chosen for the energy management of MGs in ref [30] and then the distributed battery and ultra-capacitor have been applied in order to provide scalability of the energy management. In [31], an algorithm for cooperative power dispatching among MGs in an MMG system with purpose of minimizing the operational cost of the system is developed. Authors in [32] proposed a day ahead EMS for the MMG system considering hybrid ac/dc MGs, named nested energy management system. Authors in [33], presented an EMS for a MMG based DN, according to a priority list method which sets seller or buyer roles to each MG based on the energy demand and supply difference. Ma *et al* [34], have proposed a distributed algorithm as an EMS in MMG system with high penetration of renewable based DERs which has the capability of handling the uncertainity. Also Sandgani and Sirouspour [35], have proposed a new multi-objective optimization model as an EMS for a MMG system alongside with a pricing regime. Analytical target cascading theory (ATC) is selected as a distributed approach for solving the energy management problem in the active distribution networks which is composed of the MGs in [36]. Impact of the network loss on the optimum energy management of the multi MG based distribution network has been investigated in ref [37] with considering the presence of the renewable resources in the network.

The energy management problem in an MMG based DN could be counted as a challenging issue in the power systems operation. Decisions of each entity have an impact on the operation of the other entities. Considering the network in the MMG system, makes the problem even more complicated. Contemplating the congestion in the lines of the network also affect the costs of the MGs and local units. As reviewed and the main contributions of the recent articles are explained, the impact of the congestion problem on the optimum energy management of the multi MG based distribution network has not been attended. However as a reason of load growth in the network, the occurrence of the congestion problem is probable recently. Therefore, it is needed to evaluate the impact of the mentioned problem in the energy management of the network and also the suitable solution should be determined for dealing with the problem of congestion.

In this paper, in order to investigate the importance of the congestion problem in the optimum energy management of the multi MG based DN, at first, the effect of power flow limitations in the operational costs of the MMG based DN would be discussed. Obviously, adding a constraint to an optimization problem, causes a penalty in the value of the objective function. In this optimization problem, each MG tries to trade electrical energy with the DN with power flow limitations. Thus, it is expected that the benefits of the MGs decrease. Afterwords, in order to dealing with the congestion problem, tie lines among the MGs are set. In fact, all of the MGs are considered as an integrated unit with the central controller. Accordingly, a comparison is done to define that whether considering the MGs working as an integrated unit is beneficial or not.

The main contributions of this paper can be categorized as follows:

- Modelling a power flow constrained EMS for the MMG based DN.
- Observing the impact of congestion problem on the benefits of the MGs' and the DN.
- Comparing the operation of the MGs with tie lines, working as independent units with working as an integrated unit.
- Analyzing the impact of adding tie lines to the benefits of the DN and MGs.

The rest of the paper is categorized as follows: The detailed formulation of DGs, ESS and power flow constraints have been expressed in section 2. The proposed energy management approach has been discussed in section 3 and section 4 includes simulation and obtained results of that. Finally, section 5 contains conclusion part of the paper.

2. SYSTEM CHARACTERISTICS

As mentioned, the growth of the load and penetration of the renewable energy sources in the MMG based DN cause to consider the congestion problem as a momentous issue. Congestion problem can affect the optimum energy management of the MGs and the DN. Therefore, it is needed to analyze its impact on the MMG based DN's energy management and then, the practical solution should be mentioned in order to deal with this problem.

The DN and the MGs involve DGs (renewable and dispatchable), ESSs, loads, which are modeled separately in the following subsections.

A. DG unit

In this approach, diesel generator is considered as a dispatchable unit and wind turbine (WT) and Photovoltaic (PV) units are considered as renewable units. It is assumed that, renewable units have no cost and the amount of their output power for the specific time of day ahead has been forecasted [38,39] previously, whereas for the dispatchable units, the related constraints can be formulated as follows:

$$P_{DG}^{min} \times w_{diesel} \leq P_{DG,t}^{diesel} \leq P_{DG}^{max} \times w_{diesel} \tag{1}$$

$$P_{DG,t}^{diesel} - P_{DG,t-1}^{diesel} \leq Ramp^{up} P_{DG}^{max} \tag{2}$$

$$P^{diesel}_{DG,t-1} - P^{diesel}_{DG,t} \leq Ramp^{down} P^{max}_{DG} \quad (3)$$

Constraint 1 illustrates the maximum and minimum permissible limit for the generated power of the particular DG. Constraints 2 and 3 emphasize on the ramp up and ramp down limitation of each DG.

The cost function of a diesel generator follows a quadratic function of its generated power and can be expressed as follows:

$$Cost^{diesel}_{DG,t} = A_1 (P^{diesel}_{DG,t})^2 + A_2 (P^{diesel}_{DG,t}) + A_3 \quad (4)$$

Furthermore, in order to avoid numerous shutting down or starting up of diesel generator, a start up cost has been considered as below:

$$C_{stup} = y(t) \times (Start^{Up}_{Cost}) \quad (5)$$

$$y(t) = max[(w_{diesel}(t) - w_{diesel}(t-1)), 0] \quad (6)$$

Equation 6 shows the change in the status of the generator. Accordingly, the overall cost of the diesel generator is defined using below equation:

$$Cost_{DG,i,t} = C_{stup} + Cost^{diesel}_{DG,t} \quad (7)$$

B. Energy Storage System

The MIP formulation of each ESS is systemized as follows:

$$U^{ch}_t P^{min}_{B,ch} \leq P_{B,ch,t} \leq U^{ch}_t P^{max}_{B,ch} \quad (8)$$

$$U^{dis}_t P^{min}_{B,dis} \leq P_{B,dis,t} \leq U^{dis}_t P^{max}_{B,dis} \quad (9)$$

$$U^{ch}_t + U^{dis}_t \leq 1 \quad (10)$$

$$SoC_{B,t} = SoC_{B,t-1} + (\eta^{ch}_B P_{B,ch,t} - P_{B,dis,t} / \eta^{dis}_B) * \Delta t \quad (11)$$

$$SoC^{min}_B \leq SoC_{B,t} \leq SoC^{max}_B \quad (12)$$

Constraints 8 and 9 demonstrate the limitation of the charging and discharging of the unit. Constraint 10 highlights the fact that charging and discharging of the unit cannot be occur simultaneously. State of charge (SoC) of ESS in each time interval is calculated according to the equation 11 and also its permissible limitation is illustrated in equation 12.

C. Power flow constraints

In the recommended approach for energy management of each individual entity, power flow constraints not only have been considered in the distribution network, but also they have been implemented for each MG.

For the particular node like *i* at each entity (DN, MGs), which is shown in fig. 1, the power flow constraints can be written as follows:

$$P^{renew}_{DG,i,t} + P^{diesel}_{DG,i,t} + P_{B,dis,t} + \sum_{l \in i_{back}} P_{line,l} = \sum_{l \in i_{ahead}} (P_{line,l,t} + R_l I^2_{line,l} + P_{load,l,t}) + P_{B,ch,t} \quad (13)$$

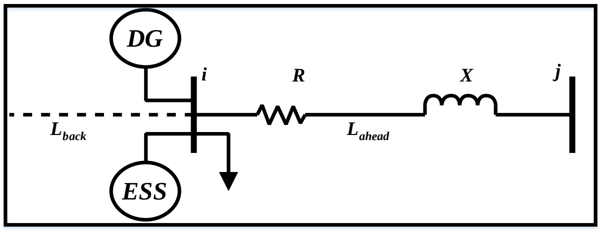

Fig. 1. shematic of the network node

$$Q^{diesel}_{DG,i,t} + \sum_{l \in i_{back}} Q_{line,l} = \sum_{l \in i_{ahead}} (Q_{line,l,t} + X_l I^2_{line,l} + Q_{load,l,t}) \quad (14)$$

$$P_{load,i,t} = P^{demand}_{load,i,t} - P^{curt}_{load,i,t} \quad (15)$$

$$Q_{load,i,t} = Q^{demand}_{load,i,t} - Q^{curt}_{load,i,t} \quad (16)$$

$$V^2_i - V^2_j = \beta_{i,j,l} \times [2R_l P_{line,l,t} + 2X_l Q_{line,l,t} + R_l I^2_{line,l,t} + X_l I^2_{line,l,t}] \quad (17)$$

$$I^2_{line,l,t} + V^2_{j,t} = P^2_{line,l,t} + Q^2_{line,l,t} \quad (18)$$

$$V_{min} \leq V_i \leq V_{max} \quad (19)$$

$$|I_{line,l,t}| \leq I^{max}_{line} \quad (20)$$

Constraints 13-16 illustrate the active and reactive power balances at the particular node. The voltage drop in each line has been formulated in constraint 17 and the bond between current and power of each branch has been shown in equation 18. Voltage limitation has been expressed in equation 19. Finally, constraint 20 is utilized in order to show the allowable amount for current passing in each line. The last two constraints represent the security constraints of the system. In the operation of the power systems, it is desired to avoid violation of these inequalities to ensure the security of the system [40].

It is noteworthy to mention that, when congestion at a particular line occurs, it means that maximum allowable current is passing from that line. In addition, loads are considered to be sheddable and it may be possible that coordinator of each entity cuts the loads when congestion takes place.

3. DAY - AHEAD ENERGY MANAGEMENT SCHEDULING OF EACH ENTITY

In this section, objective functions of each individual entity and their corresponding constraints have been discussed. The energy management problem has been done in three layers. At the first step, each MG schedules its DG units and ESS and informs the DN operator (DNO) about its shortage or surplus power in each period of time. Then, in the second step, the DNO performs energy management optimization of the DN according to the obtained results from MGs. In this part, as mentioned, the DN suffers from congestion problem and it may influence the amount of the power, which should be bought (sold) from (to)

MGs. Finally, in the last part, each MG reschedules its energy management according to the obtained results from DN.

The objective function of each MG and its related constraints are formulated as follows:

$$\min: \quad Z_{MG_{\chi}} = \sum_t \sum_i Cost_{DG,i,t} + \sum_t (price^{DN}_{buy,t} P^{lack}_t - price^{DN}_{sell,t} P^{extra}_t) + \sum_t \sum_i price^{curt}_t P^{curt}_{i,t} \tag{21}$$

$$\text{Constraints} = \begin{cases} \text{DG units} & (1)-(4) \\ \text{ESS units} & (5)-(9) \\ \text{Power flow} & (10)-(17) \end{cases}$$

As shown, the objective function for each MG contains four terms. The first term refers to the cost of the powers, which are generated by DGs. The second and third terms indicate the cost and revenue of power trading between each MG and the DN. The last term demonstrates the cost of loads, which are curtailed.

The similar cost function is also can be written for DN as follows:

$$\min: Z_{DN} = \sum_t \sum_i Cost_{DG,i,t} - \sum_{\chi} \sum_t (price^{DN}_{buy,t} P^{lack}_{\chi,t} + price^{DN}_{sell,t} P^{extra}_{\chi,t}) + \sum_t \sum_i price^{curt}_t P^{curt}_{i,t} + \sum_t price^{up}_t P^{up}_t \tag{22}$$

$$\text{Constraints} = \begin{cases} \text{DG units} & (1)-(4) \\ \text{ESS units} & (5)-(9) \\ \text{Power flow} & (10)-(17) \end{cases}$$

As can be seen the cost of trading power with upstream network is also added to the cost function of the DN.

As described, in this process, each MG has no connection with its adjacent MG and only it can trade energy with the DN. Therefore, the amount of trading power among MGs in this process should be considered zero. In this process, since, the DN suffers from congestion problem, it may not provide each MG's desired power, which is calculated at the first layer for each period of time and thus, it may lead to increase the cost of each MG in the third step because of deviation from its optimum scheduling.

In order to deal with the mentioned problem, in this paper, it is recommended that all of the MGs are controlled from the unique center and it can also be possible to trade power among them. The recommended approach is shown in fig. 2 schematically.

As it can be interfered from this fig., the MGs have both data and power transactions among them and they are controlled with a central controller. In this circumstance, MG controller (MGC) performs the energy management optimization of all MG according to the gained information from each MG about their DG, ESS and loads as follows:

$$\min: \quad Z_{total,MG} = \sum_{\chi} Z_{MG_{\chi}} \tag{23}$$

$$\text{subject to :}$$

$$\text{All constraints of each MG}$$

Then the MGC informs the DNO about its shortage and surplus power in each time slot. After that, the DN should provide power at the nodes, where each MG has been connected to the DN in a way that sum of the provided powers becomes equal to the requested power of the MGC. Finally, MGC distributes the obtained power from the DN among the MGs based on their required power using the possibility of trading power among them. Hence, the proposed method can easily neutralize the effect of DN's congestion problem on the energy management of each MG and it can reduce the costs of each one. Figure 3 shows the different steps of the proposed hierarchical energy management of the multi MG based DN.

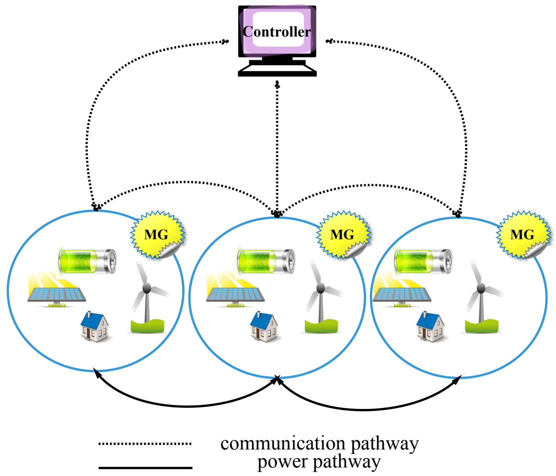

Fig. 2. Centralized multi microgrid schematic

4. SIMULATION AND RESULTS

In this section, simulations in a test system are done to examine the effectiveness of the proposed approach. Solver BARON in GAMS software is employed to perform the energy management. MGs 1 and 2 consist of PV generation units, WTs, dispatchable DERs, i.e. diesel generator and ESS. The third MG, have no dispatchable DER and the only generation units are WTs and PV generation units alongside the ESS.

These MGs are considered in a modified version of IEEE 33-bus distribution test system, which is depicted in fig.4 and network's data can be found in [41].

As mentioned earlier, the simulations would be done in three different cases. In case one, the security constraints are neglected. In the second case, the security constraints of voltage and line power flows are taken into consideration, for the DN. In case three, it is assumed that there are tie lines between the MGs, which can operate independently from the DN.

The information for the diesel generators is illustrated in table 1

Table **??** shows the characteristic of the used battery in the MGs and DN. Also hourly buying and selling prices are shown in fig. 5.

- Case 1:

As mentioned, in this case the security constraints are relaxed. Results of the first layer of the EMS is illustrated in fig. 6. The output schedules of diesel generators, ESSs, PV systems and WTs are shown in the mentioned figure. It is shown that in hours with higher electricity price, the EMS has tried to raise the power production of the dispatchble units and have started

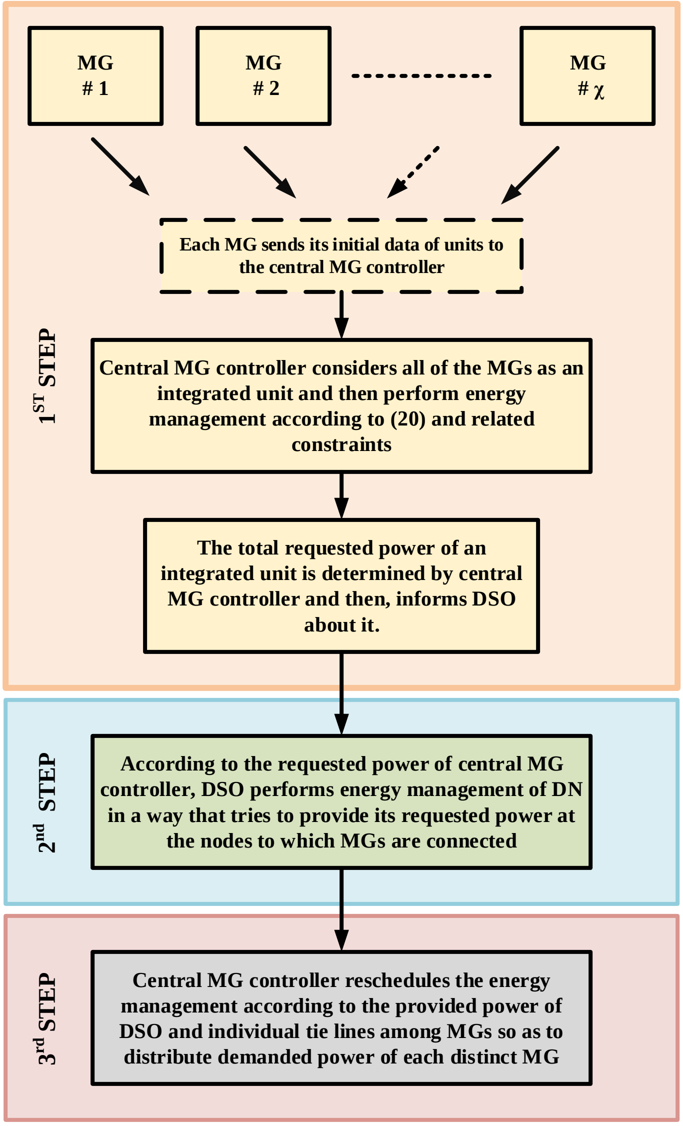

Fig. 3. schematic of the proposed method for energy management

Table 1. diesel generator data

Parameter	MG1	MG2	DN
A_1	18	15	12
A_2	90	85	75
A_3	0	0	0
$Start^{Up}_{Cost}$ (\$)	200	200	150
Ramp-up/down rate (MW/h)	1.3	1.2	1.2
Maximum Capacity (MW)	1.6	2	3

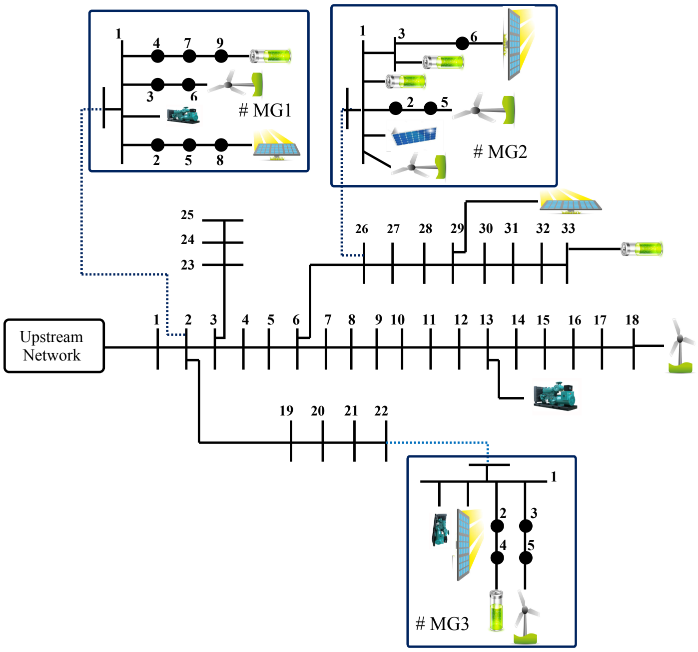

Fig. 4. The MMG based test system

Table 2. Energy storage system parameters

Parameter	MG1	MG2	MG3	DN
Capacity (MWh)	1	1	1	3
Initial Energy (MWh)	0.2	0.2	0.2	1.2
Final Energy (MWh)	0.5	0.5	0.5	1
Converter Capacity (KW)	500	500	500	750
Converter Efficiency	98	98	98	99

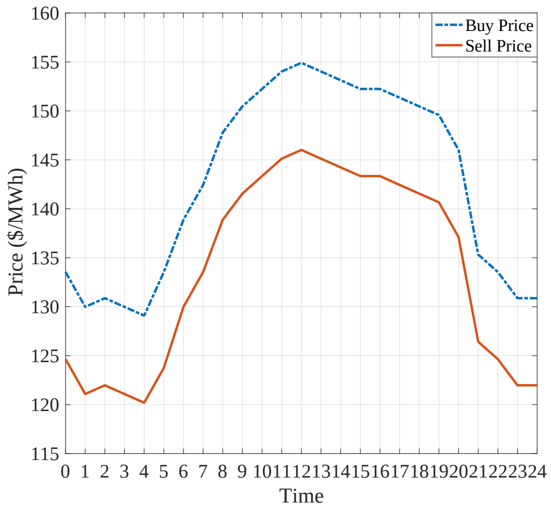

Fig. 5. hourly cost of buying and selling of electrical power

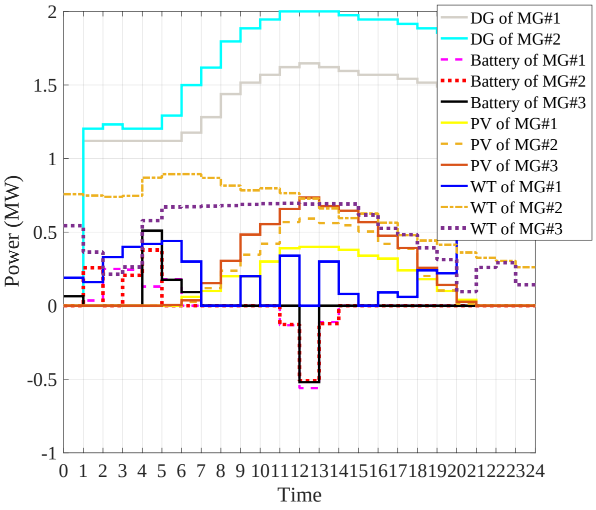

Fig. 6. output schedules of the MGs in local optimization in cases 1 and 2

to discharge the ESSs. For instance at noon hours, which have the highest trading price, the diesel units of both MGs 1 and 2 are working in their maximum capacity and the ESSs of all the MGs are in discharging mode. This is due to the fact that the EMS tries to minimize the operational cost. However, in hours with lower price (i.e. hour 4), diesels are not working in their maximum capacity and the batteries are in charging mode. Moreover, table 3, contains the shortage and surplus amount of power in each MG and the total cost of each MG.

Again according to this table, it is desirable for the MGs to sell their extra power to the upper network in hours with higher energy price and buy electricity in times with lower price (i.e. hour 12 and hour 0). The overall cost of three MGs equals to 3619$.

After informing the DNO about the schedules of the MGs, it starts a global EMS neglecting the security constraints. The output schedules of the entities of the DN is shown in fig. 7. The total cost of the DN is 8200$.

Due to the fact that security constraints have been neglected in this case, the MGs are free to sell all desired power to the DN.

- Case 2:

In this case the security constraints are considered in the DN optimization problem. Results of the first layer of the EMS would be the same as fig.6 and table 3. The reason is that MGs are small in comparison with the DN and they do not face congestion problem in their lines. Thus, considering security constraints does not affect the schedule of the MGs in the first layer.

The output schedules of the units of the DN is depicted in fig. 8.

Likewise case 1, in this case again the EMS tries to reduce the operational costs by transferring power purchase to low price times and increment in power generation in high price hours (i.e. hours 12 and 0). In comparison with the case 1, power transactions with upper grid are reduced. This is due to congestion problem and the DN is not free to sell/buy its desired amount of energy. Also in this case the operational cost has been raised to 10980($) which is a result of adding constraints to the optimization process. In case 3, a solution to indemnify the raise in operational cost would be suggested.

Table 3. surplus and shortage amount of power of the MGs in local optimization in cases 1 and 2

Time	MG1		MG2		MG3	
	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus
T0	1.145	0	0.907	0	0.126	0
T1	0	0	0	0.043	0.261	0
T2	0	0	0	0.307	0.233	0
T3	0	0	0	0.063	0.432	0
T4	0	0	0	0	0.263	0
T5	0	0	0	0.595	0	0
T6	0	0.186	0	0.828	0	0.128
T7	0	0.301	0	1.316	0	0.384
T8	0	0.318	0	1.53	0	0.521
T9	0	0.446	0	1.485	0	0.701
T10	0	0.189	0	1.633	0	0.723
T11	0	0.73	0	1.87	0	0.8
T12	0	1.058	0	2.15	0	1.386
T13	0	0.913	0	1.68	0	0.824
T14	0	0.585	0	1.435	0	0.796
T15	0	0.469	0	1.365	0	0.644
T16	0	0.509	0	1.19	0	0.456
T17	0	0.312	0	1.01	0	0.325
T18	0	0.316	0	0.745	0	0.086
T19	0	0.335	0	0.573	0	0
T20	0	0.33	0	0.491	0.263	0
T21	0	0.37	0	0.116	0.215	0
T22	0	0.26	0	0.276	0.128	0
T23	0	0	0	0	0.368	0
Cost	2795.1		1658		-834	
Total cost			3619			

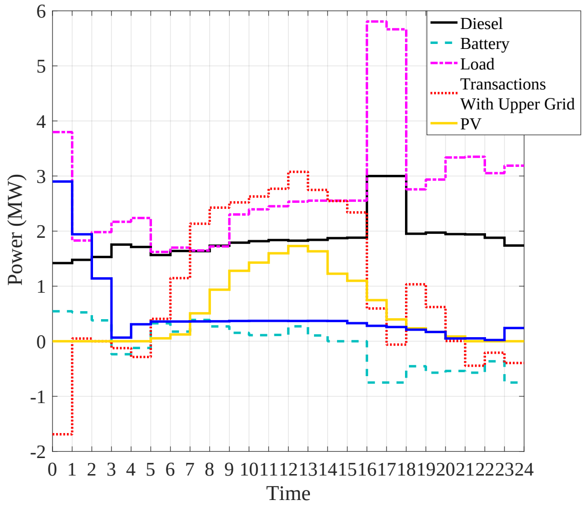

Fig. 7. distribution network output schedules in case 1

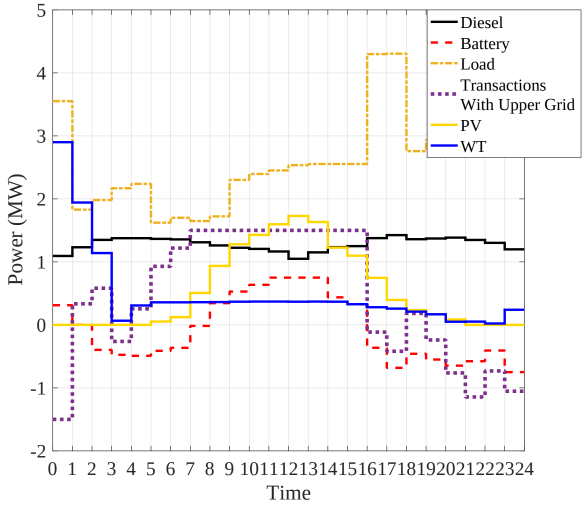

Fig. 8. distribution network output schedules in case 2

- Case 3:

In this case in order to compensate the financial losses of the MGs, tie lines between the MGs are taken into consideration. Two modes of operation can be assumed. In the first mode, MGs are considered as individual units who can decide on selling or buying their power through the tie lines or the upper DN. In the best condition, the results of this mode of operation would be the same as local optimization of the case 1.

In the second mode, an MGC is responsible to determine the output schedules of the units as an aggregated unit. Fig. 9 depicts the output schedules of the diesel generators of the first and the second MGs and the total power of the WTs, PV units and the ESSs.

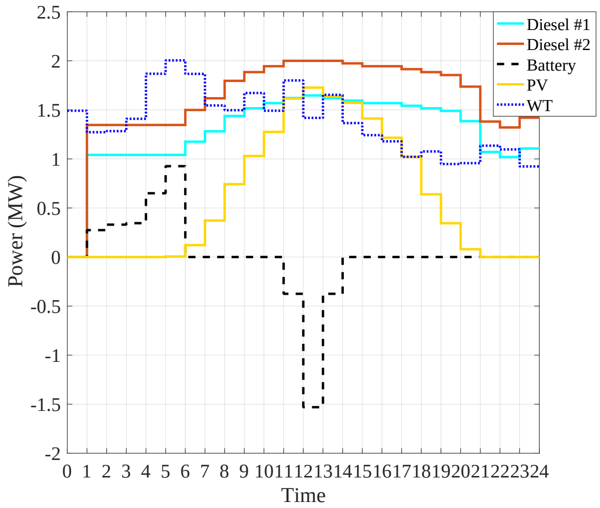

Fig. 9. Output schedules of the aggregated MGs in local optimization in case 3

Likewise previous cases, the EMS have reduced the operational costs by tuning the generation raise in high price times and power purchase raise in lower price times.

In addition, fig.10 indicates the total amount of shortage or surplus power of the aggregated system.

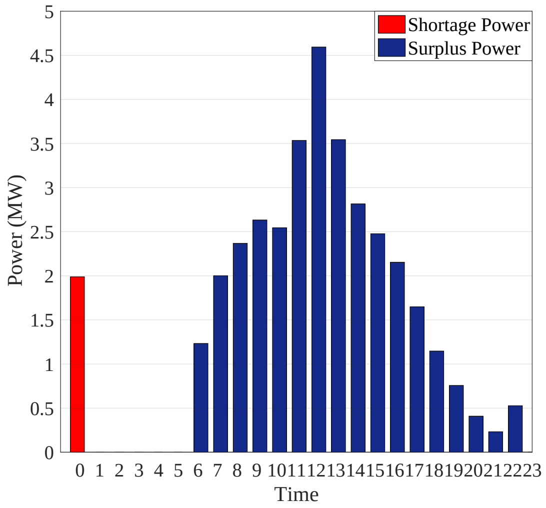

Fig. 10. Surplus and shortage amount of power of the MGs in local optimization in cases 1 and 2

In this case, the aggregated MGs and establishment of the tie lines, have reduced the shortage power and increased the surplus amount of energy and except for hour 0, the MGs would not face power shortage in their schedule. The overall cost of the aggregated MGs in this case equals to 3574$ which indicates a reduction in the total cost of three MGs as mentioned in case 1. The MGC, divides the difference between the costs in individual operation and aggregated operation, and dispatches it among the MGs which may encourage the MG owners to participate in aggregated form. In this case, the aggregated MGs are free to inject or buy their power from three candidate nodes, which is determined by the security constrained EMS. This strategy again is a coping method to minimize the unfavorable aspects of considering security constraints.

Fig. 11 shows the output schedules of the DN in this case. The cost of the DN in this case is 10270$ which is also reduced in comparison with case 2.

Fig. 12 illustrates the amount of power delivered to or bought from each MG.

In case 1, due to relaxing the security constraints, each MG can sell or buy its prescheduled amounts of power from the local EMS. Thus the costs and schedules of the MGs would be the same as local optimization process. Whereas in case 2, the MGs are unable to sell or buy their desired amount of power to or from the DN. Accordingly, their operating cost would increase which is unlikely by the MG owners. Although in case 3 the total cost of the DN is higher than that in case 1, the costs of the MGs are the same as relaxed form of the EMS. Thus, By installing tie lines, and selecting appropriate strategy for the operation of the MGs, the operational cost of the DN alongside the MGs is reduced. Table 4 indicates this fact.

At last, It is noteworthy to mentioned that the discussed simulation process has been done in GAMS software under windows 64-bit 10 using 2.9 GHz Core i7 CPU. In addition, the applied solver is CONOPT. As mentioned in the formulation section, the proposed approach for energy management of multi MG based distribution network has been done in three different

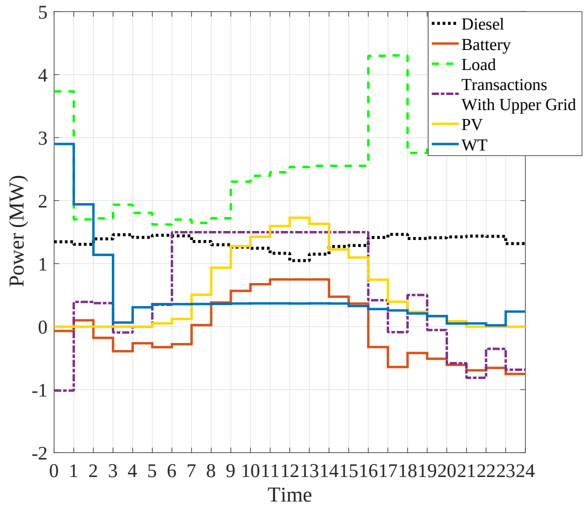

Fig. 11. distribution network output schedules in case 3

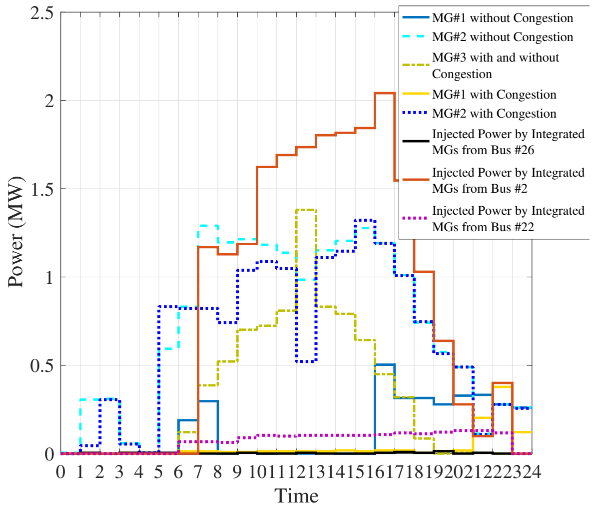

Fig. 12. schedules of the power trading with MGs in different cases

Table 4. Costs MGs and DN after rescheduling

Item	MG1	MG2	MG3	DN
WO congestion($)	2795	1658	-834	8200
With congestion($)	2976	1924	-546	10980
Considering Tie Lines($)	2182	1643	-849	10270

steps. The computation time for the first step in which central MG controller performs energy management of the all MGs is 22 sec. This time for second step is 12 sec and finally for last step takes 24 sec.

5. CONCLUSION

In this paper, a hierarchical method of energy management has been selected. First, each MG performs a local optimization to determine its schedule. In the second stage, the DN performs an energy management based on the received data from the MGs. Finally, a rescheduling would be executed to determine the final programs of the units. Later, the impact of security constraints and consequently, congestion problem in the network of an MMG system, is evaluated in the EMS of the MGs and the DN. Three case studies have been considered. In the first case study, all security constraints have been relaxed. In the second and third case studies, the security constraints have been taken into consideration. Results showed the higher cost of all the units considering security constraints and facing the congestion problem in comparison with the relaxed EMS. In order to deal with this financial loss, installing tie lines between the MGs, which their power flows are controlled by the MGC, has been supposed. Contemplating the tie lines, has indicated the lower operational costs for both the DN and the MGs. It is concluded, the implementation of the proposed method, neutralizes economic loss caused by the contingencies for the MGs and somehow for the DN.

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