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**Research Article**

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# Optimal Energy Scheduling of Isolated Medium Voltage DC Distribution Microgrid Considering the Economic Operation

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**Abstract** The interminably growing demand for DC electricity in a world nowadays claims an efficient and reliable power supply system. Therefore, the need for Distributed energy resources such as diesel generators, wind energy, solar energy and fuel cell stacks can be combined within a medium voltage DC microgrid to provide energy in the form of medium voltage direct current to the consumers in a sustainable manner. To ensure more economical energy supply, in this article, an energy management system is produced of isolated medium voltage direct current microgrid considering operating cost and scheduling the optimal operation for each of energy distributed resources mentioned. Moreover, the proposed economic scheduling used a particle swarm optimization algorithm (PSO). The efficacy of PSO is compared with other mathematics technique in terms of performance measurement indices, which are cost functions of electricity probability. The results show that the proposed technique manage the operation of micro grid under different operating conditions and reducing the cost of microgrid compared without applying optimization techniques on energy production units.

**Keywords** Energy, Micro grid, Economic operation, Management

## 1. Introduction

Many sites are often located in remote and isolated places. However, it is important to have a secure, reliable and stable power generation supply for running operations successfully. Most technological interest in the medium voltage DC current (MVDC) systems with several publications as in [1-5]. Various power equipment manufacturers have also introduced new products on this technology. Examples include ”Mitsubishi” Electric’s inverter system with all “Sic” power modules, and “ABB’s” medium voltage dc products and systems. (MVDC) systems are commercially available. At the present time, it is expected to be used more commonly in the future, and its applications for renewable and conventional energy power systems needs a more flexible and detailed analysis. Compared to (MVAC) distribution networks, the (MVDC) distribution networks has shown great potential in transmission capacity, power quality, conversion efficiency, electromagnetic interference, power dispatch and operating stability as in [6-7]. Therefore, in recent years, (DC) distribution network is gradually attracting the attention of researchers. (MVDC) distribution micro grids supply a future dc homes lead to several advantages over employed AC-grids as in [8]. Therefore, (MVDC) systems can supply stable and high quality power for sensitive loads. As a result, (MVDC) systems can efficiently integrate DC generation units such as renewable energy sources (RES) and various loads such as, sensitive electronic loads and electric vehicles (EV) [9]. As a result, there is a greater need for higher scale and higher voltage levels in distribution systems as (MVDC) systems [10]. The challenge for microgrids in general is maintaining stable and secure of supply, this problem is becoming exacerbated by the increase in variable renewable capacity such as wind and solar energy. Using a (MVDC) technology to connect microgrids with each other and with the wider network delivers the precise and active control needed for independence, optimization and security. Medium-voltage DC (MVDC) power systems and DC distribution technologies have made a comeback and keep gaining a commendable increase in research interests and industrial applications using renewable energy resources, this lead to , MVDC power systems trends to exploit distributed generations and local electrical loads [11]. In this paper, an approach has been simulated to schedule the renewable and conventional energy resources in a medium DC voltage microgrid considering optimal power management between them, the addition also reduces the operating cost of system. In this research, to maximize the economic benefit and minimizes the operational cost, microgrid is incorporated with diesel generator, fuel cell stacks, and renewable energy resources. Therefore, (PSO) algorithm has been considered to attain the optimal dispatch which minimizes the generation cost. The main goal of the paper is to formulate the fuel cell and diesel generator cost equations for (24 hour) time analysis considering different operational conditions at each of renewable energy resources. In addition to that, this research proposes the efficacy of the proposed method has been verified by comparing it with other mathematic technique proposed in the literature. The proposed method manages to attain lower operating cost without the loss of power supply at any interval of time.

## 2. Medium DC voltage microgrid system

An isolated medium DC voltage microgrid system contains three subsystems: the load demand, the power generation and the distribution subsystem. They are dependent on the climatic conditions and the consumer services. This section presents the power and cost models for the solar, wind, diesel generator and fuel cell stacks as the distributed energy resources of the power generation subsystem, the load profile of the residential area as the demand subsystem and the microgrid itself is configured as the power distribution subsystem. The combination of different renewable energy resources improves the system efficiency and reduces the requirements of conventional energy resources. The general schematic of the microgrid system containing these systems is as shown in Figure 1.

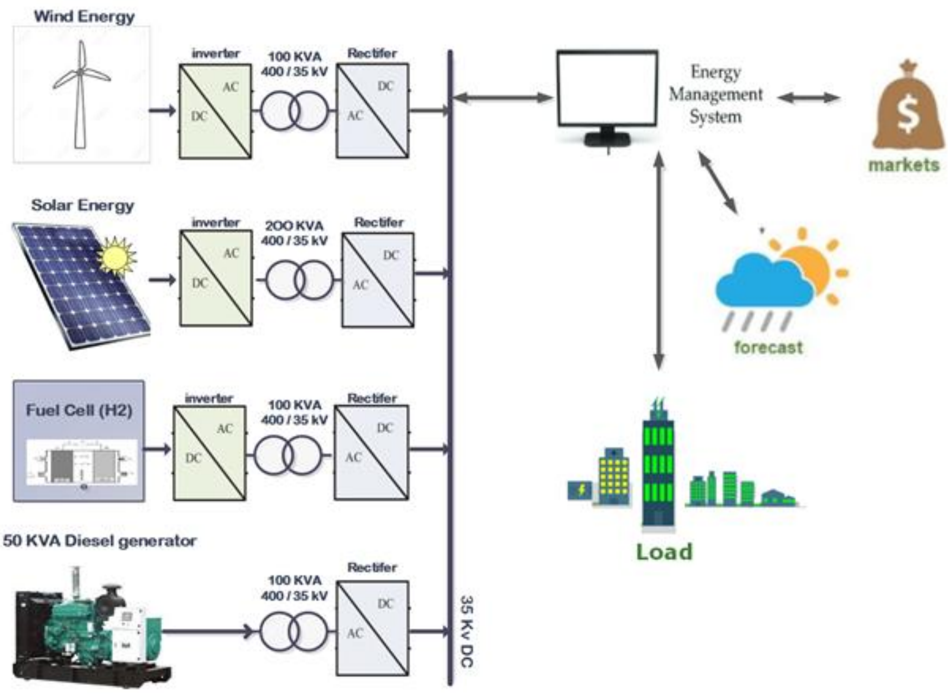


*Figure 1: General schematic of medium DC voltage microgrid*

### 2.1. Wind turbine (WT) model

The power model of a wind turbine (WT) measures the power as a function of the hourly wind speed, the mechanical power extracted by the wind turbine is expressed in (1) as [12]

$$Pm = 0.5\ \rho\ A\ Cp\ V_w^3 \qquad (1)$$

In order to investigate the system performance within a lot range of wind velocities with an MPPT controller.

### 2.2 Solar PV model

The PV panel is equipped with an MPPT controller, the power output is expressed as a function of irradiance and temperature using the following formula in equation (2).

$$P_{PV,\,out} = p_{pv,\,rated} * \frac{I}{Iref} * [1+ Kt \{(T_{amb} + (0.0256 * I) - T_{ref}\}] \quad (2)$$

### 2.3 Diesel generator

Diesel generator is the secondary power generation source for the microgrid mentioned when the renewable energy resources cannot fulfill the required electricity load demand. The conventional generator and serves as a backup energy source and improves the system reliability by smoothing the power generation from the renewable energy source. The cost of the diesel generator in terms of power dispatch is expressed by equation (3) as seen in [13-14].

$$Cdi = \alpha_{di} + \beta_{di} P_{di} + \gamma_{di} P_{di}^2 \quad (3)$$

### 2.4 Fuel cell stack

A solid oxide fuel cell (SOFC), the fuel input is natural gas, and their rated capacities are relatively more suitable for distributed generator system. It also contributes to sharing electrical energy with the Diesel Generator when renewable energy sources cannot fulfill the required power loads. The cost of the stack in terms of power dispatch is expressed by equation (4) as in [15-16].

$$CFC = \alpha_{FC} + \beta_{FC} P_{FC} + \gamma_{FC} P_{FC}^2 \quad (4)$$

## 3. Energy management strategies.

The power management strategies of the microgrids have an impact on the operational behavior of the system regardless of grid-connected mode or isolated mode of operation. However, in the isolated mode the power generated from the distributed generators must fulfil the load demand for a reliable operation; otherwise, the system will face load shedding The unavailability of renewable resources at certain times of the day will force the diesel generator and fuel cell to operate and dispatch optimal power. Thus, an efficient power management strategy should be required to dispatch the power at the lowest cost to serve the load considering the technical constraints of the system. The power strategy for economic scheduling in this research has been summarized into the following scenarios:

Scenario 1: Renewable resources are capable to provide a sufficient energy to fulfill the load demand.

Scenario 2: the extra energy will generate by renewable resources is dissipated as a dump load.

Scenario 3: Renewable resources can't fulfill the required load. The algorithm will decide to run the diesel generators or discharge the fuel cell depending on the required load and the cost accumulated in two conventional energy resources.

## 4. Performance measurement models of MVDC microgrid

### 4.1 Cost of electricity

The cost of electricity is calculated as an indicator of the economic profitability of microgrid. The electricity cost is the ratio of the sum of the costs associated with diesel generators ($C_{di}$) and the fuel cell stack ($C_{FC}$) to the total load of the day. The electricity cost is measured between conventional generation's resources and load for the 24-hour analysis expressed by equation (5)

$$\text{Cost of electricity} = \frac{\sum_{t=1}^{T} (Cdi+CFC)}{\sum_{t=1}^{T}(Pload)} \quad (5)$$

### 4.2 Constraints

The energy management strategy of the system has been optimized by meeting the following constraints:

#### 4.2.1 Diesel generator constraint

The power generated from the diesel generator must be within the upper and lower limits.

$$P_{Di,\,i,\,min} \leq P_{Di,\,i}(t) \leq P_{Di,\,i,\,max} \quad (6)$$

**4.2.2 Fuel cell constraint**

The power generated from the fuel cell must be within the upper and lower limits.

$$P_{FC,\,i,\,min} \leq P_{FC,\,i}(t) \leq P_{FC,\,i,\,max} \quad (7)$$

**4.2.3 Power balancing constraint**

The primary constraint in the power system is to balance of load demand and power generated at each time step expressed by equation (8)

$$Pload(t) - Ppv(t) - Pwi(t) - PFC(t) - Pdi(t) = 0 \quad (8)$$

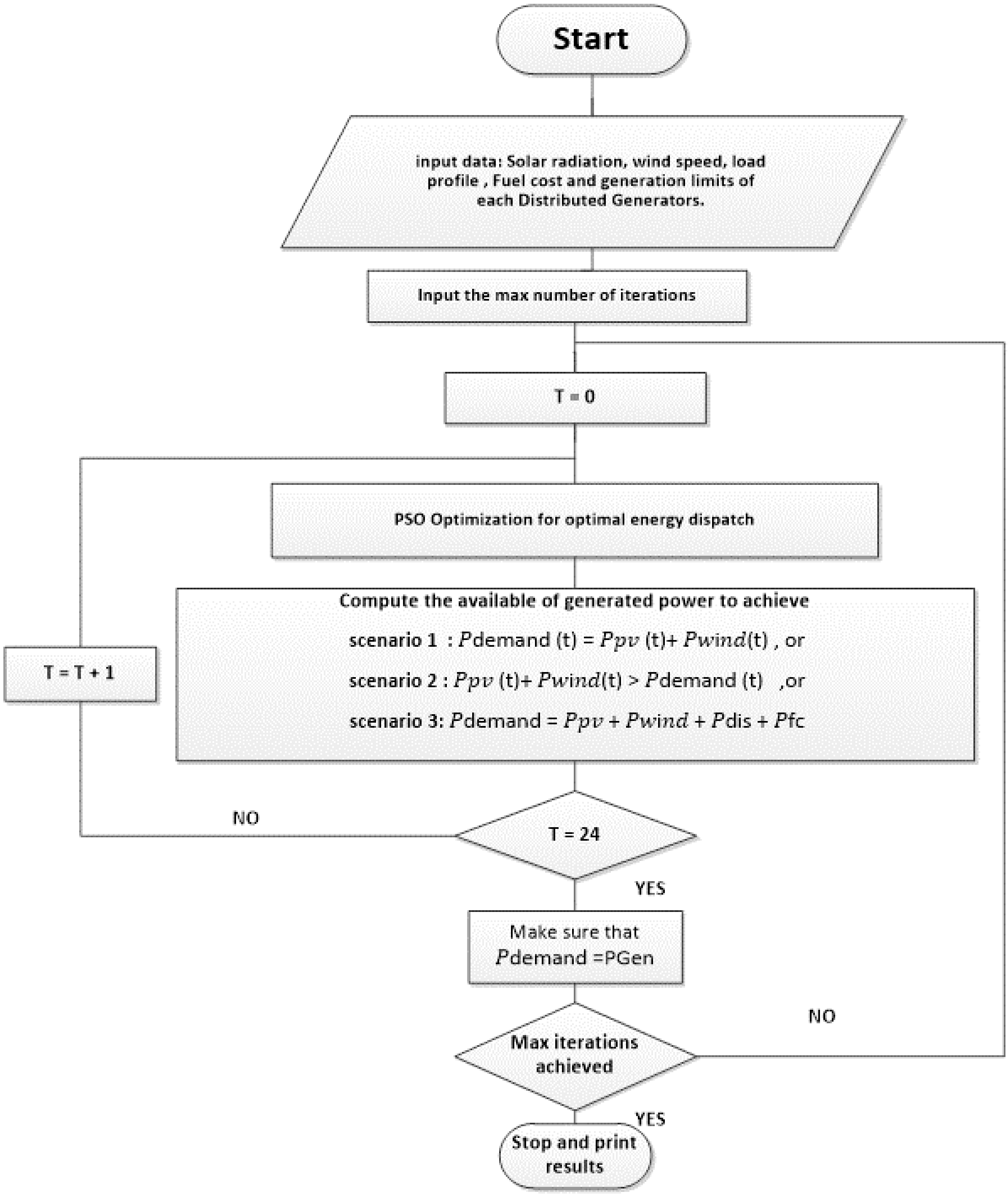


*Figure 2: Flow chart of the proposed (PSO) method*

**5. Proposed methods**

The proposed methods calculates economic scheduling of the conventional energy resources as per load demand at each hour. The economic dispatch is based on the power management strategies such as (LAGRANGE Optimization and PSO Optimization) when there isn't enough energy through the renewable sources than that required by loads such as in scenario 3 of the power management strategies. The proposed optimization algorithms dispatches the optimal power from the diesel generator and the Fuel cell depending on the cost equations of the respective distributed power resources and the load demand at the specific hour. The flowchart of the proposed method (PSO) is shown in Figure 2.

**6. Results and Discussion**

A typical medium voltage microgrid is analyzed in this study to illustrate the performance of the proposed energy management strategies. The microgrid consists of 150 kW photovoltaic and 50 kW wind turbine system as a renewable resources and conventional resources as (fuel cell, diesel generator), the data for the diesel generator and fuel cell are taken from [17, 18] .The parameters for the photovoltaic and wind turbine are represented in Tables (2, 3) respectively. The proposed strategies is formulated in MATLAB (R2018a) and run on the personal computer 2.6 GHz core i7 processor with 16 GB RAM. The generation system is designed to meet the load of small residential isolated area with the peak load of 180 kW has been taken in this study. The load demand at some of the instances time are higher than the combined wind and solar generation. Thus, the generator and fuel cell will be operated at these instances.

**6.1 Case (1): System is running at autumn season**

The microgrid load profile and renewable energy generation graphs are shown in Figure 3.

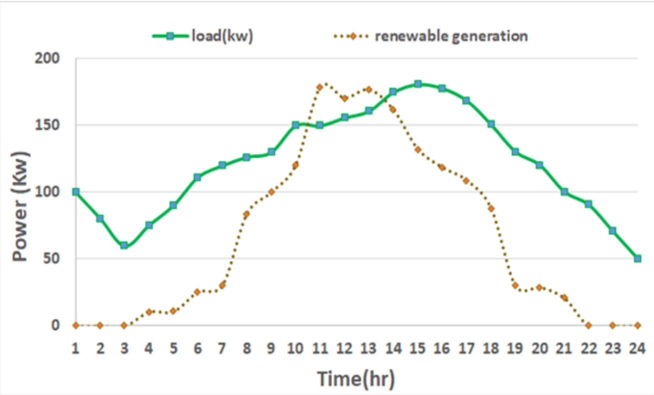


*Figure 3. The generation of RES and load profile for a day*

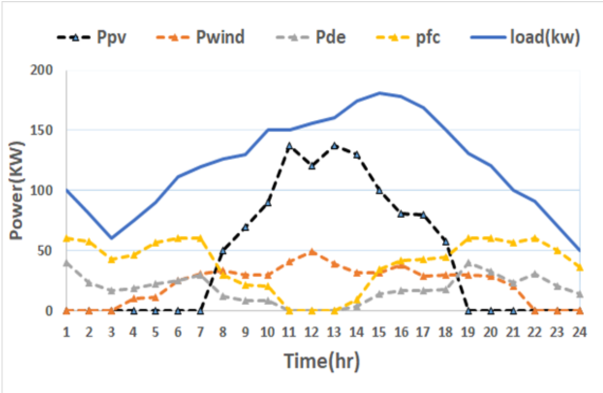


*Figure 4: The generation of DER energy and load*

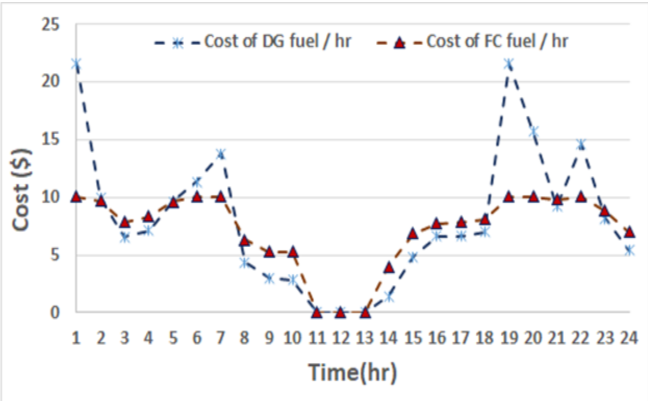


*Figure 5: The optimized cost of generator and fuel cell*

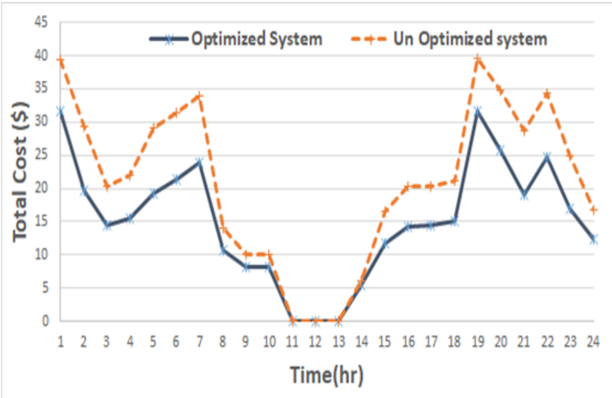


*Figure 6: Proposed optimized system cost reduction*

The load demand at some of the instances time are higher than the combined wind and solar generation. Thus, the generator and fuel cell will be operated at these instances. The Renewable energy resources, diesel generator and fuel cell have to satisfy the load demand at all instances. However, there are some instances where the renewable generation cannot satisfy the required load, according to instability of weather forecast as (wind speed, sun irradiance) thus, there will be power mismatch between the generation and load demand. The proposed optimization algorithms dispatches the optimal power between diesel generator and fuel cell. Figure 4 shows the generation power curve of the distributed energy sources and the load profile. Figure 5 shows the power needed and the running cost consumed from diesel engine and fuel cell in each hour during a day. The proposed microgrid system was compared before and after power dispatched and the total cost at all instances are plotted in Figure 6.

**Table 2:** Parameters of solar PV

| Component Parameter | Value |
|---|---|
| Rated power(KW) | 150 |
| Parallel string | 100 |
| Series connected module/string | 10 |
| Initial Capital cost($/kW) | 3000 |
| Lifetime (year) | 10 |

**Table 3:** Parameters of wind turbine

| Component Parameter | Value |
|---|---|
| Rated power(KW) | 50 |
| Cut in speed (m/s) | 5 |
| Cut out speed (m/s) | 12 |
| Rated speed | 10 |
| Initial Capital cost ($/kW) | 2000 |
| Lifetime (year) | 10 |

**6.2 Case (2): System is running at winter season**

The generation system is designed also in this study case to meet the load of small residential isolated area with the peak load of 180 kW. The microgrid load profile and renewable energy generation graphs are shown in figure (7).

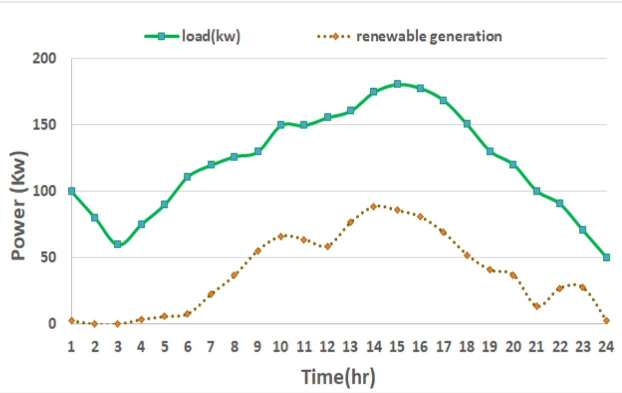


*Figure 7: The generation of RES and load profile for a day*

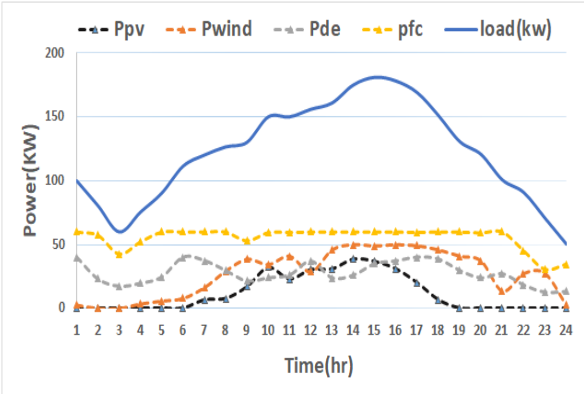


*Figure 8: The generation of DER energy and load*

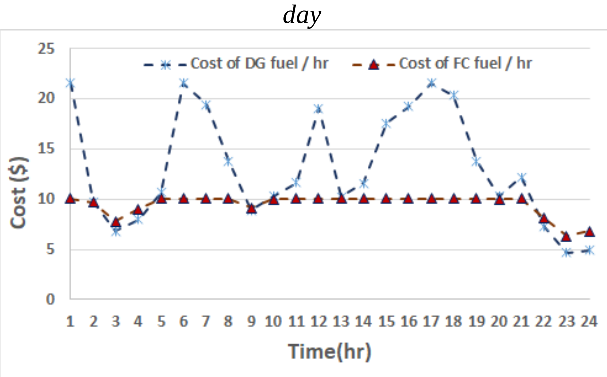


*Figure 9: The optimized cost of generator and fuelcell*

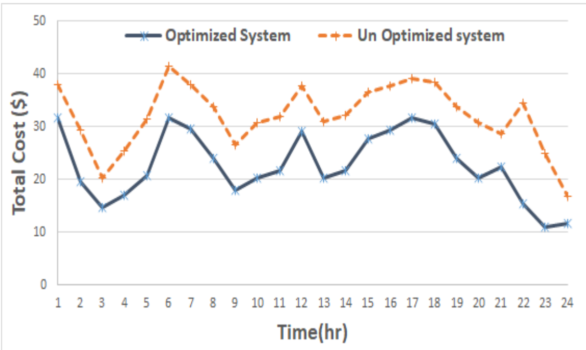


*Figure 10: Proposed optimized system cost reduction*

At this case we study a day in winter season ,The Renewable energy resources can't satisfy the load demand at all instances as seen in Figure 7 according to instability of weather forecast as (sun irradiance is very low at this season) thus, there will be power mismatch between the generation and load demand. The load demand at this case study are higher than the combined wind and solar generation. Thus, the generator and fuel cell will be operated and sharing power at these instances. As in Figure 8, to obtain stable micro grid operation. The proposed optimization algorithms dispatches the optimal power between diesel generator and fuel cell, calculate the power needed and the running cost consumed from diesel engine and fuel cell in each hour during a day (Figure 9). The proposed microgrid system was compared before and after power dispatched and the total cost at all instances are plotted in Figure 10.

### 6.3 Case (3): System is running at spring season

The microgrid load profile and renewable energy generation graphs are shown in Figure 11. At this case we study a day in Spring season, The Renewable energy resources can satisfy the load demand at some of instances as seen in Figure 11, according to stability of weather forecast as (sun irradiance and wind speed are moderate) thus, there will be power match between the generation and load demand at sunny times, but at cloudy and dark times there will be a power mismatch between renewable generations and load profile, The load demand will be high than combined wind and solar generation. Thus, the generator and fuel cell will be operated and sharing power at these instances. As in Figure 12, to obtain stable micro grid operation at all times of a day. The proposed optimization algorithms dispatches the optimal power between diesel generator and fuel cell, calculate the power needed and the running cost consumed from diesel engine and fuel cell in each hour during a day (Figure 13). The proposed microgrid system was compared before and after power dispatched and the total cost at all instances are plotted in Figure 14.

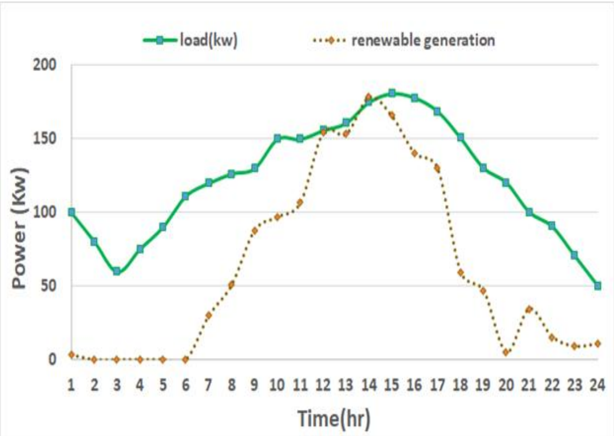


*Figure 11: The generation of RES and load profile for a day*

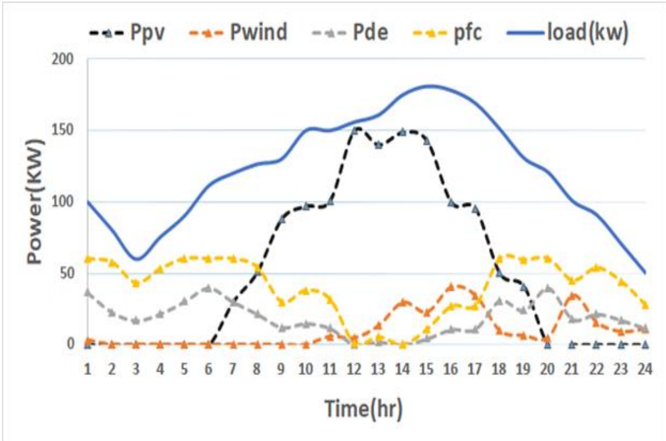


*Figure 12: The generation of DER energy and load*

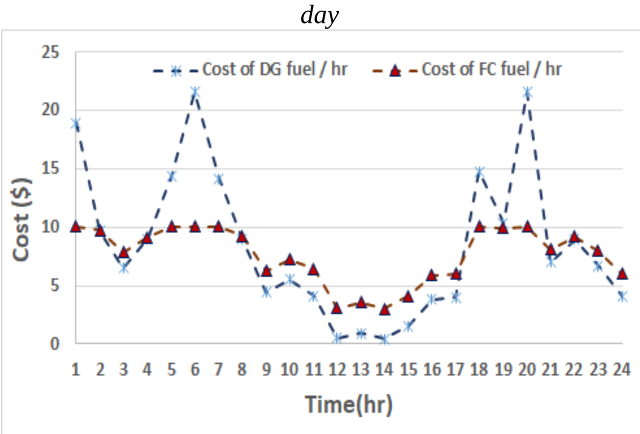


*Figure 13: The optimized costof generator and fuel cell*

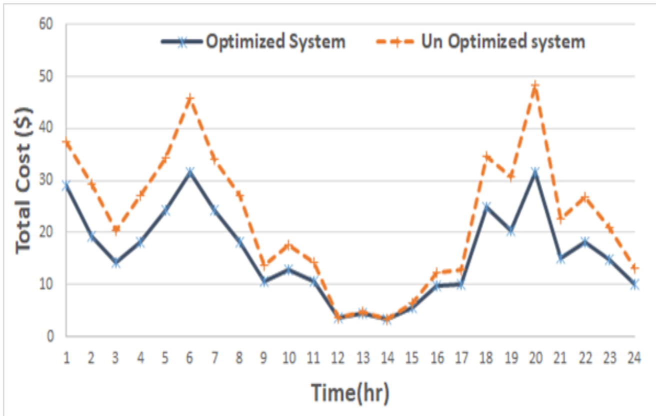


*Figure 14: Proposed optimized system cost reduction*

### 6.4 Case (4): System is running at summer season

The generation system is designed also in this study case to meet the load of small residential isolated area with the peak load of 180 kW. The microgrid load profile and renewable energy generation graphs are shown in Figure 15. At this case we study a day in summer season, The Renewable energy resources can't satisfy the load demand at more of instances than another seasons as seen in Figure 15, due to wind speed is very low compared with another one, so Wind power will be small at a lot of days in this season. The sun irradiance is optimum this brings us to high generation from PV resource can participation a power at more sunny times. Some instance there will be a whole power mismatch between both renewable generations and load profile. Thus, the need to produce energy is very necessary at these times of the day to meet the load requirements, diesel generator and fuel cell will be operated and sharing power at these instances. As in Figure 16, to obtain stable micro grid operation at all times of a day. The proposed optimization algorithms dispatches the optimal power between diesel generator and fuel cell, calculate the power needed and the running cost consumed from diesel engine and fuel cell in each hour during a day (Figure 17). The proposed microgrid system was compared before and after power dispatched and the total cost at all instances are plotted in Figure 18.

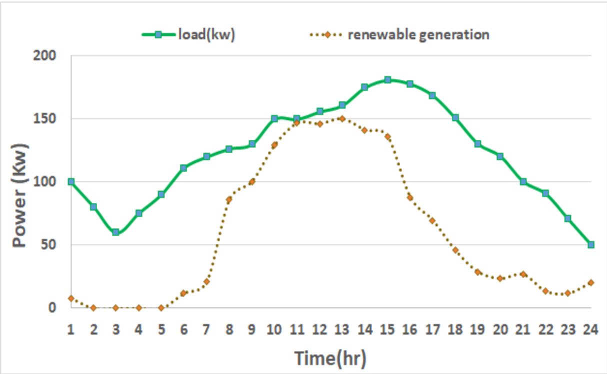


*Figure 15: The generation of RES and load profile for a day*

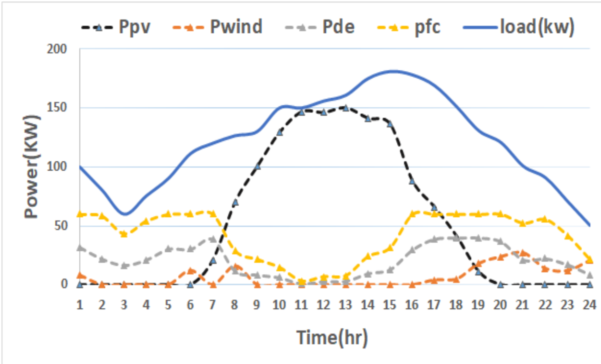


*Figure 16: The generation of DER energy and load*

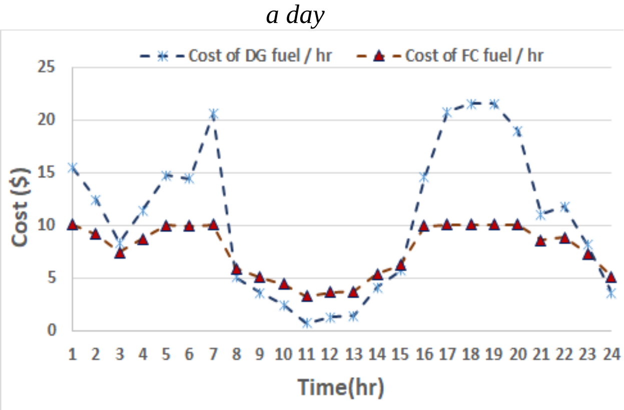


*Figure 17: The optimized cost of generator and fuel cell*

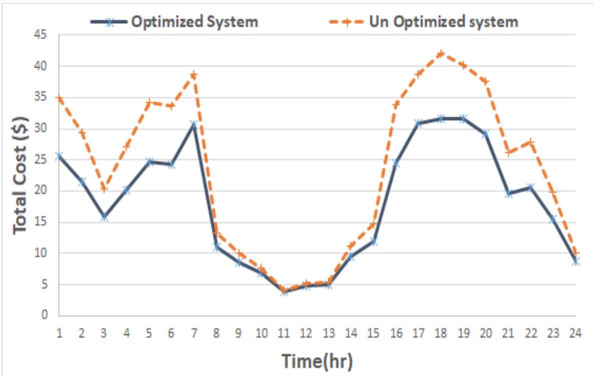


*Figure 18: Proposed optimized system cost reduction*

## 7. Conclusion

As more energy supplies are predicted to utilize distributed energy resources such as renewable resources and conventional resource, the economic aspects of the energy production in the isolated microgrid has to be taken into consideration to ensure a reliable and sustainable service to consumers. The present study has solved the economic scheduling problem between the diesel generators and the fuel cell stacks considering operating time cost. One of the strengths of the proposed method is to share the optimum power needed with minimum operating cost between two of conventional sources during critical hours. PSO optimization algorithm was implemented to solve the economic Dispatch problem. The simulation results reveal that the microgrid faces the load shedding without generator and fuel cells resulting in instability. Furthermore. The proposed system was compared before and after power dispatched control and 50% reduction in operating cost has been recorded. Thus, the obtained results show that an economic scheduling will reduce the operating cost of the microgrid. The energy scheduling approach presented will help the independent power plant operators to perform the electricity efficiently.

**References**

[1]. H. Mirzaee, S. Dutta, S. Bhattacharya, (2010). A medium-voltage DC (MVDC) with series active injection for shipboard power system applications, IEEE Energy Conversion Congress and Exposition (ECCE), 2865-2870, 12-16 Sept.

[2]. Y. Tang and A. Khaligh, (2011). Bidirectional hybrid Battery/Ultracapacitor Energy Storage Systems for next generation MVDC Shipboard power systems, IEEE Vehicle Power and Propulsion Conference (VPPC), pp. 1-6, 6-9 Sept.

[3]. F. Barati, D. Li, and R. A. Dougal, (2013). Voltage regulation in medium voltage DC systems, IEEE Electric Ship Technologies Symposium (ESTS), pp. 372-378, 22-24 April.

[4]. M. Bash, R. Chan, J. Crider, C. Harianto, J. Lian, J. Neely, S. Pekarek, S. Sudhoff, and N. Vaks, (2009). A Medium Voltage DC Testbed for ship power system research," IEEE Electric Ship Technologies Symposium, ESTS 2009. pp. 560-567, 20-22 April.

[5]. V. Arcidiacono, A. Monti, and G. Sulligoi, (2014). Generation control system for improving design and stability of medium-voltage DC power systems on ships, IET Electrical Systems in Transportation, vol. 2, no. 3, pp. 158-167, September.

[6]. Ma J., Geng G., Jiang Q, (2016). Two-time-scale coordinated energy management for medium-voltage DC systems, IEEE Trans. Power Syst., 31, (5), pp. 3971–3983.

[7]. Lee J. Rashkin, Jason C. Neely, David G. Wilson, Steven F. Glover, Norbert Doerry, Stephen Markle, (2019). Energy storage design considerations for an MVDC power system, Published online: 04 Nov.

[8]. M. Stieneker, J. Butz, S. Rabiee, H. Stagge, and R. W. D. Doncker, (2015). Medium-Voltage DC Research Grid Aachen, In: International ETG Congress, Die Energiewende - Blueprints for the new energy age; Proceedings of Nov.

[9]. L. Gan and S. Low, (2014). Optimal power flow in direct current networks, IEEE Trans. Power Syst., vol. 29, no. 6, pp. 2892–2904, Nov.

[10]. G. Reed, B. Grainger, A. Sparacino, R. Kerestes, and M. Korytowski, (2012). Advancements in medium voltage DC architecture development with applications for powering electric vehicle charging stations," in Proc. IEEE Energytech, May.

[11]. X. Li, M. Zhu, M. Su, J. Ma, Y. Li and X. Cai, (2020). Input-Independent and Output-Series Connected Modular DC–DC Converter With Intermodule Power Balancing Units for MVdc Integration of Distributed PV, in IEEE Transactions on Power Electronics, vol. 35, no. 2, pp. 1622-1636, Feb.

[12]. M. M. Hussein, T. Senjyu, M. Orabi, M. A. Wahab, and M. M. Hamada, (2012). Simple maximum power extraction control for permanent magnet synchronous generator based wind energy conversion system, International Journal of Sustainable and Green Energy, Vol. 1, No. 1, pp. 1-10, Dec.

[13]. Modiri-Delshad M., Kaboli S. H. A., Taslimi-Renani E., and Rahim N. A., (2016). Backtracking search algorithm for solving economic dispatch problems with valve-point effects and multiple fuel options, Energy, vol. 116, pp. 637–649, May.

[14]. Li Y., Yang Z., Li G., Mu Y., Zhao D., Chen C., et al., (2018). Optimal scheduling of isolated microgrid with an electric vehicle battery swapping station in multi-stakeholder scenarios: A bi-level programming approach via real-time pricing," Applied Energy, vol. 232, pp. 54–68, Nov.

[15]. Li Y., Yang Z., Li G., Zhao D., and Tian W., (2019). Optimal scheduling of an isolated microgrid with battery storage considering load and renewable generation uncertainties, IEEE Transactions on Industrial Electronics, vol. 66, pp. 1565–1575, Dec.

[16]. Mbungu N. T., Bansal R. C., Naidoo R., Miranda V., and Bipath M., (2018). An optimal energy management system for a commercial building with renewable energy generation under real-time electricity prices, Sustainable Cities and Society, vol. 41, pp. 392–404, Aug.

[17]. Li Z., Zang C., Zeng P., Yu H., and Li S., (2018). Agent-based distributed and economic automatic generation control for droop-controlled AC microgrids," IET Generation, Transmission & Distribution, vol. 10, pp. 3622–3630, Oct.

[18]. Marouane Lagouir, Abdelmajid Badri, Yassine Sayouti, (2019). Development of an Intelligent Energy Management System with Economic Dispatch of a Standalone Microgrid, Journal of Electrical Systems 15-4, 568-581, Aug.