Dibya Bharti[1,*], **Mala De**[2],

J. Electrical Systems 14-2 (2018): 63-75

Regular paper

Power Flow Guided Optimal Resource Allocation in Microgrid

Journal of Electrical Systems

The integration of renewable energy resources (RERs) and technological advancements has modernized electrical power system network from conventional grid to microgrid. Diversity in operating condition and increase in energy demand has significant impact on power distribution as well as on its utilization. Efficient and optimal allocation of available resources becomes a challenge as generations are mostly renewable based which are intermittent in nature and also dispersed in nature. An allocation technique is required to achieve optimal utilization of available resources like distribution lines and generations and to control the flow of power through shortest path. This paper establishes an optimization based resource allocation method to efficiently manage available generation at any load condition while achieving minimum operating cost. The contribution of the proposed allocation method is twofold, maximum distribution capacity utilization is achieved by maximizing the amount of power flowing through individual lines while loss minimization is achieved by sending power through shortest path as loss is directly proportional to distance travelled by power. Additionally, the proposed methodology also suggests proper controller location to maintain desired power flow through the shortest path between each generator and load pair. The proposed methodology is tested on an interconnected microgrid network consisting of RERs as well as on conventional grid.

Keywords: Microgrid, Resource Allocation, Shortest Path, Power flow constraints, Optimization, Genetic Algorithm (GA)
Article history: Received: 27 April 2018, Accepted: 30 July 2018

1. Introduction

In recent years traditional architecture of electric power system is being modified into smart grids with integration of Distributed Energy Resources (DERs) for efficiently managing power demands in environment friendly manner. Microgrids are subsystems of smart grids which operate efficiently in parallel with or independently from the main traditional electric grid. Energy management is an essential part in planning and operation of generating units whose objectives are sustainable development and cost savings. Microgrid encourages increased integration of distributed and renewable energy resources (RERs) like wind turbines and photovoltaics (PV) with existing power system to achieve improved power quality and reliability. Generation units of microgrids consist of RERs as well as conventional power sources. Electricity generations by renewable energy resources are intermittent which leads to power outage depending on weather conditions (e.g. Power output of PV will be very insignificant in cloudy condition or at night and wind does not blow consistently always). Hence, conventional power generations are required in microgrids to avoid power interruption due to natural variations in RERs [1]. Choice of available sources allows distribution system operator to decide most suitable source for individual loads at any operating condition which is defined as resource allocation.

Resource allocation deals with allocating suitable power source to a load depending on availability at minimum operating costs and any other predefined condition like reduction in greenhouse gas emission etc. [2-3]. In many cases, scheduling method is also responsible for allocating suitable resources to demand utilities present in the system [4-8]. Such a

---

[*] Corresponding author: Dibya Bharti, Research Scholar, Department of Electrical Engineering, National Institute of Technology Patna, India, E-mail: dibya_minu1@rediffmail.com

[1,2] Department of Electrical Engineering, National Institute of Technology Patna, India, Pin 800005

[2] Assistant Professor (E-mail: mala.de.power@gmail.com), Department of Electrical Engineering, National Institute of Technology Patna, India, Pin 800005

scheduling scheme becomes tedious in heterogeneous environment because of diverse operating conditions. Microgrids are heterogeneous structure because it consists of different types of generation units. Its heterogeneity continues to increase as newer technology continues to emerge. In literature, there exist various methods for efficiently allocating and utilizing available energy resources in context of microgrids [9-15].

A resource allocation method proposed in [9] for electricity trading in multi-agent system based microgrids proves to be superior over conventional trading methods which are either priority-based or round-robin based resource allocation methods . Most of the existing market based methods consider only profit making trading strategy. Distributed resource allocation methods are usually designed on the basis of customer's participation frequency and amount of their load demand which are known as priority-based methods [10-12]. These methods may lead to energy starvation situation for customers having lower priority.

In literature, there exist some energy management schemes (EMS) that involve design of control strategies and decision-making mechanism for suitable resource allocation [2, 13-15]. Control strategies for EMS within microgrids are hierarchical and redesigned from transmission level [13-15].

Differential evolution is also applied for scheduling in microgrid [16-17] with advance PV generators, energy storage system and micro-turbines. There are various deterministic, stochastic, heuristic and hybrid approaches for scheduling in microgrid [18-19]. An optimization based resource allocation is proposed in [20] where GA is used to choose a suitable path from source to a certain demand. It optimizes a cost function based on distance but is suitable only for smart grids with transshipment network. In transshipment network, the flow of power is interrupted by at least one intermediate bus between source and load. And most importantly, it assumes power will flow through the optimized path irrespective of the physical parameters of the network.

A reputation based centralized energy allocation method is proposed for microgrid but a separate DC power line is required to transfer renewable energy from consumer to energy management centre [21]. EMS proposed in [22] is applicable only for hybrid energy storage system for DC microgrid operating in islanded mode. For smart electricity market, a greedy agent based resource allocation methodology is proposed in [23] which minimizes purchasing costs of buyers by using evolutionary algorithm.

Implementation of control strategies based EMS is a complex task as large number of control devices are required which needs efficient computational techniques. There is no standard methodology and load classifying methods for resource management by load scheduling. This paper presents a resource allocation method to control power flow from source to load in an interconnected network topology based microgrid while obeying physical power flow conditions of the network. This is achieved by minimization of system loss cost and cost of controller installation using GA. The method controls power flow path in microgrid by forcing power through shortest path, so as to achieve minimum active power loss. The cost of resource allocation is optimized in terms of number of controllers required to ensure power flow to be relevant to physical properties of the system, an aspect that most of the present resource allocation works ignore.

Next section presents the notations used in paper. Section 3 outlines and describes proposed methodology adopted for resource allocation. Section 4 presents the application of the proposed method to different test systems whereas section 5 presents comparison of GA with other optimization method for implementation of the resource allocation, Section 6 outlines application of the method for radial system. Finally, Section 7 concludes the work.

2. Notation

The notation used throughout the paper is stated below:-

P_{gi} : Generator active power output;

P_{li} : Load active power;

P_k : Active power injected at bus ‘k’;

Q_{gi} : Generator reactive power output;

Q_{ci} : VAR source installed at bus ‘i’;

Q_{li} : Load reactive power;

Q_k : Reactive power injected at bus ‘k’;

V_{gi} : PV bus voltage;

V_i : Bus voltage;

V_k : Voltage at bus ‘k’;

Y_{ki} : Admittance matrix entry between buses ‘k’ and ‘i’;

P_{ik} : Apparent power between buses ‘k’ and ‘i’;

R_{dc} = conductor dc resistance (μΩ/ft);

ΔT_d = conductor temperature rise due to dielectric loss (□);

Y_c = loss increment due to conductor skin and proximity effects;

R_{CA} = thermal resistance between conductor and ambient usually called thermal-ohm-feet (□-ft/W);

T_C = conductor temperature (□);

T_A = ambient temperature (□);

k = constant depending on Y_c, resistivity and cross-sectional area of conductor;

L = length of conductor;

3. Optimization Problem for Resource Allocation

There are two major operational challenges in microgrid: control strategy and power management. The proposed method allocates available resources to individual loads which come under power management. The primary focus of the proposed work is to fulfill load requirements at minimum operating cost while maximizing capacity usage of power lines.

3.1 Capacity of Power Lines

In electrical network, capacity of power lines refers to the thermal capacity. Electrical power transmission through a network causees power loss (I^2R) which generates heat leading to temperature rise in conductor above ambient temperature. Rate of heat transfer is directly dependent on temperature difference between conductor and ambience. Based on heat transfer concepts, Neher-McGrath (NM) equation is proposed for calculation of load capability of conductors which is given by [24]:-

$$I = \sqrt{\frac{T_C - (T_A + \Delta T_d)}{R_{dc}(1+Y_c) * R_{CA}}} \Rightarrow I = \sqrt{\frac{T_C - (T_A + \Delta T_d)}{k * L^2}} . \tag{1}$$

Where, I is Ampacity or capacity of conductor to carry power continuously (in A) without exceeding its temperature rating. From (1), it can be concluded that load carrying capability of conductors depend on length of the conductor. For fixed cross-sectional area, ampacity is inversely proportional to length of the conductor.

Operating cost has different components: cost of generation and cost associated with loss. As the generators connected to the microgrid are considered to be renewable based, the genearation cost will be very small and can be neglected. Loss cost will depend on amount of loss produced by flow of power through different branches of the system.

3.2 Loss

Transmission and distribution line losses are directly proportional to resistance which again depends on length of line. If two conductors of same material and uniform cross-sectional area are connected between source node $'i'$ and load node $'j'$ then losses will be less in conductor with smaller length. Hence, if power flow follows shortest path between generation and demand, loss in transmission and distribution lines will be minimum.

As, $R_{ij} = \rho \frac{l_{ij}}{a}$ and $P_{loss\_ij} \propto l_{ij}$ (2)

Optimal resource allocation based on power flow is a multi-period problem as generation and load are time variant. Available amount of power to be allocated cannot be estimated for a long period in microgrids. Firstly, amount of available generation throughout a day is calculated from predicted weather data and grid power availability which is known day ahead. According to availability of generation flexible loads are dispatched for each hour. Once hourly generation and load patterns are available, next step is to decide on generation and load pairs that will supply and consume power. This comes under resource allocation and is the area of discussion in present paper. The optimal resource allocation is presented in this paper for resources and loads present at a particular time slot.

3.3 Problem Formulation

An electrical network may be represented by a graph $G = (V, E)$ comprising of a set of are nodes V, and a set of branches E. An element of edge set E may be considered as $e = (i, j)$ directed from bus 'i' to 'j'. Let l_{ij} denotes length between buses 'i' and 'j' and x_{ij} is set of decision variables in assigning source at bus 'i' to demand at bus 'j'.

Ther proposed method aims at minimizing cost associated with loss and maximize use of line capacity while satisfying constraints of the system. For minimization of cost associated with loss, power is dispatched from generation to demand through shortest path. The objective is to maximize line flow $(Max \sum P_{ij})$ within its limit and to minimize losses $(Min \sum P_{loss\_ij})$ by minimization of distance $(Min \sum l_{ij})$ as mentioned in (2). Hence, the objective function for proposed resource allocation problem is given as,

$$f = w_1 F_1 + w_2 F_2 = w_1 \{\max \sum_{(i,j)\in G} (P_{ij})\} + w_2 \{max \sum_{(i,j)\in G} \left(\frac{1}{l_{ij}} \right)\} \tag{3}$$

Where, $w_1 + w_2 = 1$ and w_1 and w_2 are weights of objective function whose value depends on choice of operator. Here, $w_1 = w_2 = 0.5$ is considered that is, both the objectives are given equal importance. P_{ij} represents power flow through different branches of microgrid.

Subject to

(a) Power balance at each node:

$$\sum_{(i,j)\in G} P_{ik} - \sum_{(i,j)\in G} P_{kj} = P_k \forall k \in V \tag{4}$$

(b) Power flow constraints:

(i) Active power balance : $P_{gi} - P_{li} - P_k = 0$ (5)

$$P_k = V_k \sum_{i=1}^{n} Y_{ki} V_i \cos(\delta_k - \delta_i - \theta_{ki}) \tag{6}$$

(ii) Reactive power balance: $Q_{gi} + Q_{ci} - Q_{li} - Q_k = 0$ (7)

$$Q_k = V_k \sum_{i=1}^{n} Y_{ki} V_i \sin(\delta_k - \delta_i - \theta_{ki}) \tag{8}$$

(c) Active power generation limits: $P_{gi}^{min} \le P_{gi} \le P_{gi}^{max}$ (9)

(d) PV bus voltage limits: $V_{gi}^{min} \le V_{gi} \le V_{gi}^{max}$ (10)

(e) Reactive power generation limit: $Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}$ (11)

(f) PQ bus voltage limits: $V_i^{min} \le V_i \le V_i^{max}$ (12)

(g) Line capacity limits: $P_{ij}^{min} \le \left|P_{ij}\right| \le P_{ij}^{max} \forall\ (i,j) \in G$ (13)

Line capacity constraints mentioned in (g) will assign the amount of line flow near to maximum limit by optimal use of load capability of line.

3.4 The Algorithm

The proposed resource allocation method can be described by the following steps:

Step 1: Determine available generation for intermittent sources and find demand at buses.

Step 2: Perform power flow analysis.

Step 3: Determine shortest path between each generator and load pair that obeys power flow (using Johnson's algorithm). These shortest power flow paths correspond to minimum active power loss for resource allocation to the individual loads.

Step 4: Optimize power flow at different branches by GA to minimize power loss.

Step 5: Compare directions of optimized power flow through different lines with shortest path decided at step 3 to find mismatches. Number of mismatches will decide number of controllers required to force power to flow through optimized path.

Step 7: Decide number of controllers to be installed in the system by careful observation of power flow paths of Step 3 and Step 4.

Step 8:Compare cost of controllers with reduction in loss cost by controller placement.

Step 9*:* Allocate the resource to individual load according to power directions.

4. Results and Discussions

4.1. 14-Bus System

A modified IEEE-14 bus system is used as microgrid. In this system, node 2 is assumed to be connected with a wind farm of 40MW rated capacity and node 3 has a solar plant of 60MW capacity. A new branch is added between buses 1-3 in this modified system. This simple modification in the system structure depicts complexity in the results. The microgrid is integrated with a conventional power plant (connected to grid) at bus 1 as a backup in case solar and wind generation can't meet load demands. Single line diagram of this modified test system is shown in figure 1 with direction of power flow through the lines.

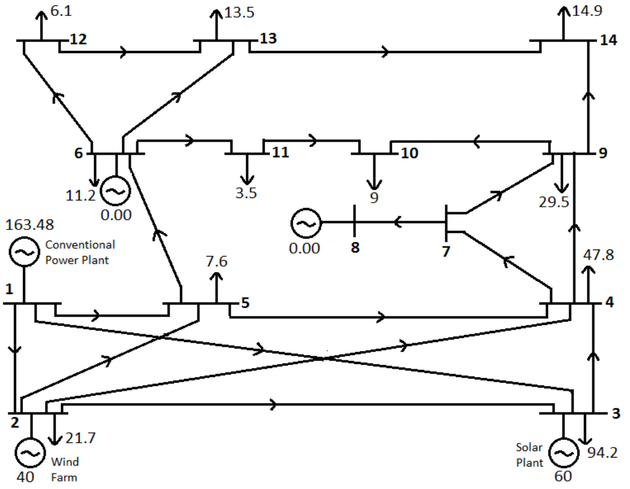

Fig. 1: Modified IEEE 14-bus test system

The system data are listed in table 1 and table 2.

Table 1 : Branch Data of Modified IEEE 14-Bus System

From Bus	To Bus	Reactance (in Ω)	Resistance (in Ω)	Impedance (in Ω)	Length (in p.u.)
1	2	0.01938	0.05917	0.0623	1.4094
1	5	0.05403	0.22304	0.2295	5.1950
1	**3**	**0.00000**	**0.04211**	**0.0421**	**0.9527***
2	3	0.04699	0.19797	0.2035	4.6060
2	4	0.05811	0.17632	0.1856	4.2025
2	5	0.05695	0.17388	0.1830	4.1419
3	4	0.06701	0.17103	0.1837	4.1582
4	5	0.01335	0.04211	0.0442	1.0000
4	7	0.00000	0.20912	0.2091	4.7338
4	9	0.00000	0.55618	0.5562	12.5902
5	6	0.00000	0.25202	0.2520	5.7050
6	11	0.09498	0.19890	0.2204	4.9895
6	12	0.12291	0.25581	0.2838	6.4245
6	13	0.06615	0.13027	0.1461	3.3073
7	8	0.00000	0.17165	0.1762	3.9875
7	9	0.00000	0.11001	0.1100	2.4903
9	10	0.03181	0.08450	0.0903	2.0439
9	14	0.12711	0.27038	0.2988	6.7632
10	11	0.08205	0.19207	0.2089	4.7280
12	13	0.22092	0.19988	0.2979	6.7441
13	14	0.17093	0.34802	0.3877	8.7771

*Newly Added line

The power flow directions for the optimized condition for modified IEEE 14-bus test system are presented in table 3. Figure 2 compares the line flow achieved by GA and power flow. We know power flow through different lines of any system depends only on physical conditions of the network i.e. voltages at nodes and impedances of lines. Hence, power flow always does not follow shortest path between source and load. Shortest path between each pair of source and load is determined on the basis of impedance present in the path. Paths between source and load pairs are also determined by using direction of power flow analysis. In table 4, shortest paths based on impedance value and power flow direction are listed. Table 5 presents resource allocation for different generations to individual loads. It is clear from table 4 that path followed in power flow analysis and shortest path based on impedance is not same in case of generator 3 to loads 5, 6, 11, 12 and 13.

Table 2: Bus Data of Modified IEEE 14-Bus System

Bus	Voltage		Generation		Load	
	Mag (p.u.)	Ang (p.u.)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1.060	0.000^*	163.48	140.25	-	-
2	1.045	-1.654	40.00	23.69	21.70	12.70
3	1.010	-1.461	60.00	-136.31	94.20	19.00
4	1.017	-5.202	-	-	47.80	-3.90
5	1.020	-4.634	-	-	7.60	1.60
6	1.070	-9.773	0.00	12.84	11.20	7.50
7	1.062	-8.416	-	-	-	-
8	1.090	-8.416	0.00	17.47	-	-
9	1.057	-10.079	-	-	29.50	16.60
10	1.052	-10.310	-	-	9.00	5.80
11	1.057	-10.171	-	-	3.50	1.80
12	1.055	-10.599	-	-	6.10	1.60
13	1.051	-10.651	-	-	13.50	5.80
14	1.036	-11.327	-	-	14.90	5.00

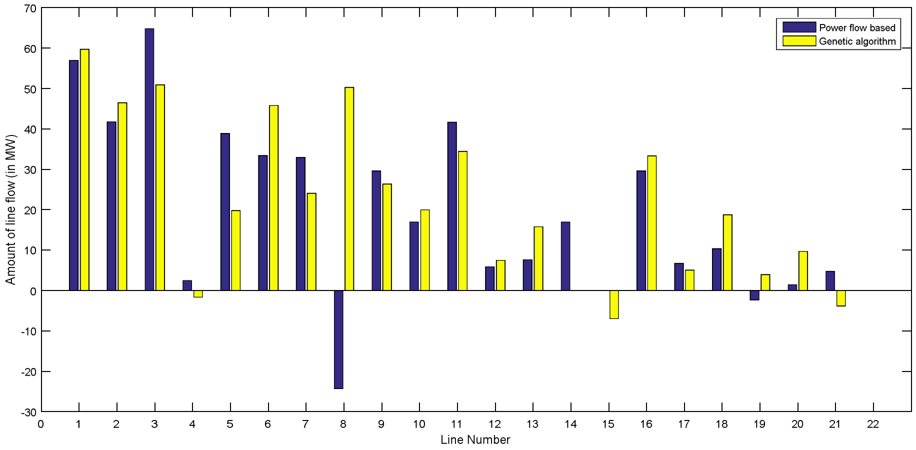

Fig. 2 : Comparison of Line Flow

From results listed in table 3, it is clear that after optimization maximum percentage change in energy flow is 575.685 between the two flows in the line connected between buses 12 and 13 in this case. This shows that load capability of conductors is being used very efficiently.

Table 3: Energy Flow in Each Line of Modified IEEE 14-Bus System

From Bus (i)	To Bus (j)	Energy flow (based on Power Flow Analysis) $E_{ij} : i \rightarrow j$	Energy flow (based on Optimization) $E_{ij} : i \rightarrow j$	%change
1	2	56.9900	59.7273	4.8030
1	5	41.7700	46.4945	11.3110
1	3	64.8200	59.9092	-7.5760
2	3	2.4500	-1.6604	-32.2280
2	4	38.8600	19.7796	-49.1000
2	5	33.4000	45.8228	37.1940
3	4	32.9300	24.0477	-26.9730
4	5	-24.2700	50.3004	107.2530
4	7	29.6100	26.3461	-11.0230
4	9	16.9600	19.9815	17.8150
5	6	41.6400	34.4179	-17.3440
6	11	5.8600	7.4546	27.2110
6	12	7.6000	15.7633	107.4110
6	13	16.9800	-0.0010	-99.9940
7	9	29.6100	33.3076	12.4870
9	10	6.7100	5.0474	-24.7780
9	14	10.3600	18.7407	80.8940
10	11	-2.3100	3.9536	71.1510
12	13	1.4300	9.6623	575.6850
13	14	4.7100	-3.8397	-18.4770

Table 4: Shortest Path Based on Impedance And Power Flow Analysis (14-bus System)

Gen	Load	Shortest Path	Path based on power flow	Gen	Load	Shortest Path	Path based on power flow
1	2	1-2	1-2	2	10	2-4-7-9-10	2-4-7-9-10
1	3	1-3	1-3	2	11	2-5-6-11	2-5-6-11
1	4	1-3-4	1-3-4	2	12	2-5-6-12	2-5-6-12
1	5	1-5	1-5	2	13	2-5-6-13	2-5-6-13
1	6	1-5-6	1-5-6	2	14	2-4-7-9-14	2-4-7-9-14
1	9	1-3-4-7-9	1-3-4-7-9	3	2	3-2	NA
1	10	1-3-4-7-9-10	1-3-4-7-9-10	3	3	3-3	3-3
1	11	1-5-6-11	1-5-6-11	3	4	3-4	3-4
1	12	1-5-6-12	1-5-6-12	3	5	3-4-5	NA
1	13	1-5-6-13	1-5-6-13	3	6	3-4-5-6	NA
1	14	1-3-4-7-9-14	1-3-4-7-9-14	3	9	3-4-7-9	3-4-7-9
2	2	2-2	2-2	3	10	3-4-7-9-10	3-4-7-9-10
2	3	2-3	2-3	3	11	3-4-5-6-11	NA
2	4	2-4	2-4	3	12	3-4-5-6-12	NA
2	5	2-5	2-5	3	13	3-4-5-6-13	NA
2	6	2-5-6	2-5-6	3	14	3-4-7-9-14	3-4-7-9-14
2	9	2-4-7-9	2-4-7-9				

Controller Selection: From results listed in table 3, we see that results of optimization violate power flow results in lines 2-3, 4-5, 6-13, 10-11 and 13-14. That means, to force power from generator to flow to load, we need to connect a controller between buses 2-3, 4-5, 6-13, 10-11 and 13-14. Otherwise, physical properties of the system will not allow the flow of power in the optimized path. By placing controller, flow of power can be forced to follow the shortest path. It is clear from table 3 that direction of power flow is different in five branches. Hence, five controllers are required to maintain the optimum flow. Additional cost of controllers and cost associated with losses are compared to find out the optimal number of controllers required to maintain desired power flow direction. But, if a controller is placed in line 4-5 only then between every pair of generation and load, direction of power flow will be through shortest path. This will lead to an improved cost. Table 5 describes the amount of generation supplied to different loads that is final resource allocation through shortest path.

Table 5: Resource Allocation for Modified IEEE 14-Bus System

	Gen 1	Gen 2	Gen 3
Load 2	0.0	21.7	0.0
Load 3	34.2	0.0	60
Load 4	29.5	18.3	0.0
Load 5	7.6	0.0	0.0
Load 6	11.2	0.0	0.0
Load 9	29.5	0.0	0.0
Load 10	9.0	0.0	0.0
Load 11	3.5	0.0	0.0
Load 12	6.1	0.0	0.0
Load 13	13.5	0.0	0.0
Load 14	14.9	0.0	0.0

Controller Cost Estimation: If optimized amount of line flow is dispatched from generation to demand through shortest path then losses will be minimized. Controllers are required at appropriate position for dispatching power through shortest path as the physical properties of the line parameters will force the power flow through a different path.

Let's assume cost of installing a controller be C_{cont}, cost of loss initially without controller be C^i_{loss} and cost of loss after connecting controller be C^n_{loss}.

Total $cost_{old} = \sum_{t=1}^{T} C^i_{loss}$

Total $cost_{new} = \sum_{t=1}^{T} C^n_{loss} + N * C_{cont} * \frac{1}{LE}$

Where, $T = 24$ (number of hours in a day); N is the number of controller to be installed; LE is the life expectancy of the controller in days.

By comparing total $cost_{new}$ and total $cost_{old}$, controller placement will be decided. If difference between $\sum C^i_{loss}$ and $\sum C^n_{loss}$ is significant then installation of controller is opted depending on cost of controller. The cost calculation have to consider the life of the controller installed and have to compare the total amount of loss reduction cost achieved by installation of this controller over the life time.

4.2. 30-Bus System

IEEE 30-bus system is considered an interconnected microgrid. In this test system, node 23 and 13 is assumed to be connected with a wind farm of 20MW and 40MW rated capacity respectively. Node 2, 22 and 27 has a concentrated solar plant of 65MW, 30MW and 30MW rated capacity respectively. Figure 3 shows the comparison of line flow achieved by GA and power flow. Some of power flow directions for most optimized condition of microgrid considered in figure 3 is presented in table 6.

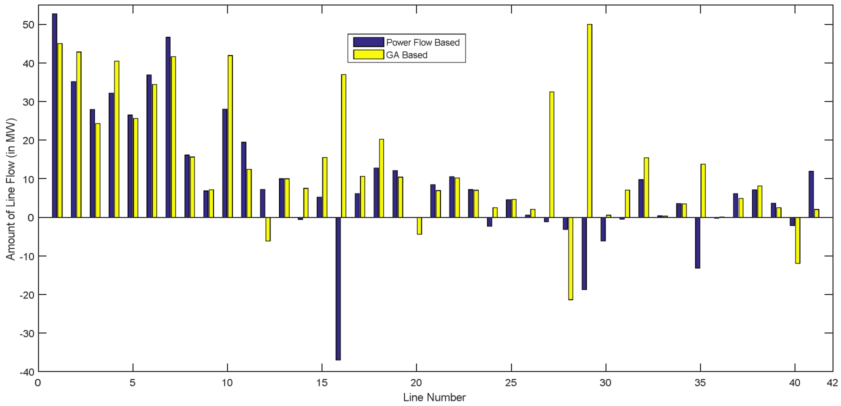

Fig. 3 : Comparison of Line Flow in 30-bus microgrid

Table 6: Shortest Path Based on Impedance And Power Flow Analysis (30-bus System)

Gen	Load	Shortest Path	Path based on power flow	Gen	Load	Shortest Path	Path based on power flow
1	2	1-2	1-2	13	2	13-12-4-2	NA
1	3	1-3	1-3	13	3	13-12-4-3	NA
1	4	1-3-4	1-3-4	13	4	13-12-4	13-12-4
1	7	1-2-6-7	1-2-6-7	13	7	13-12-4-6-7	13-12-4-6-7
1	8	1-2-6-8	1-2-6-8	13	8	13-12-4-6-8	13-12-4-6-8
1	10	1-2-6-9-10	1-2-6-9-10	13	10	13-12-16-17-10	13-12-4-6-9-10
1	12	1-3-4-12	NA	13	12	13-12	13-12
1	14	1-3-4-12-14	NA	13	14	13-12-14	13-12-14
1	15	1-3-4-12-15	NA	13	15	13-12-15	13-12-15
1	16	1-3-4-12-16	NA	13	16	13-12-16	13-12-16
1	17	1-2-6-9-10-17	1-2-6-9-10-17	13	17	13-12-16-17	13-12-16-17
1	18	1-3-4-12-15-18	NA	13	18	13-12-15-18	13-12-15-18
1	19	1-2-6-9-10-20-19	1-2-6-9-10-20-19	13	19	13-12-15-18-19	13-12-15-18-19
1	20	1-2-6-9-10-20	1-2-6-9-10-20	13	20	13-12-15-18-19-20	13-12-4-6-9-10-20
1	21	1-2-6-9-10-21	NA	13	21	13-12-16-17-10-21	NA
1	23	1-3-4-12-15-23	NA	13	23	13-12-15-23	NA
1	24	1-2-6-9-10-21-22-24	NA	13	24	13-12-15-23-24	NA
1	26	1-2-6-28-27-25-26	NA	13	26	13-12-4-6-28-27-25-26	NA
1	29	1-2-6-28-27-29	NA	13	29	13-12-4-6-28-27-29	NA
1	30	1-2-6-28-27-30	NA	13	30	13-12-4-6-28-27-30	NA

5. Comparison of Resource Allocation for Different Optimization Techniques

The proposed methodology uses GA based optimization technique. To show the usefulness of GA, a comparison with FMINCON is also presented in this section. The following table shows the application of both the methods for 14 bus test system.

For both cases of optimization, line capacity is assumed as 60MW for each line. The resultant by FMINCON shows that energy flows in almost one third of lines are at their maximum limit which is not favourable solution. But, resultants of energy flows by GA are more suitable because in this case lines are not working at their maximum limit. The amount of energy flow in each line by GA is more comparable to energy flow by power flow analysis than by FMINCON. The aim of proposed methodology is to maximize the objective function and here from results presented in table 7, it can be concluded that the value of objective function is maximum by GA (-187.9226) than by FMINCON (-275.1879). From results listed in table 3, it is clear that after optimization maximum percentage change in energy flow is 575.685 for line 12-13 in case of GA. This shows that load capability of conductors is being used very efficiently.

Table 7: Comparison of different optimization techniques for 14-bus System

From Bus (i)	To Bus (j)	Energy flow (based on Power Flow Analysis) $E_{ij}: i \rightarrow j$	Energy flow (based on Optimization) $E_{ij}: i \rightarrow j$		%change	
			GA	FMINCON	GA	FMINCON
1	2	56.9900	59.7273	60.0000	4.8030	5.2800
1	5	41.7700	46.4945	46.1300	11.3110	10.4381
1	3	64.8200	59.9092	60.0000	-7.5760	-7.4359
2	3	2.4500	-1.6604	34.2000	-32.2280	12.9591
2	4	38.8600	19.7796	-15.9000	-49.1000	-140.9161
2	5	33.4000	45.8228	60.0000	37.1940	79.6407
3	4	32.9300	24.0477	60.0000	-26.9730	82.2046
4	5	-24.2700	50.3004	60.0000	107.2530	-347.2187
4	7	29.6100	26.3461	60.0000	-11.0230	102.6342
4	9	16.9600	19.9815	-3.7000	17.8150	-121.8160
5	6	41.6400	34.4179	38.5300	-17.3440	-7.4687
6	11	5.8600	7.4546	-32.6700	27.2110	-657.5085
6	12	7.6000	15.7633	60.0000	107.4110	689.4736
6	13	16.9800	-0.0010	0.0100	-99.9940	-99.9411
7	9	29.6100	33.3076	7.1300	12.4870	-75.9202
9	10	6.7100	5.0474	52.8700	-24.7780	687.9284
9	14	10.3600	18.7407	52.8700	80.8940	410.3281
10	11	-2.3100	3.9536	45.1700	71.1510	-20.5541
12	13	1.4300	9.6623	-25.5000	575.6850	-18.8322
13	14	4.7100	-3.8397	-36.1700	-18.4770	-86.7940
Objective Function			-187.9226	-275.1879		

6. Resource Allocation in Radial System

The proposed method can be applied to any radial systemwith less number of steps and faster result can be achieved as the only available path between load and generator pair is the shortest path in most of the cases.

Consider a radial topology based microgrid network as shown in figure 4 in which concentrated solar power plant of 90MW rated capacity is connected at bus 5 and wind farm of 60MW rated capacity is integrated at bus 9. The microgrid is connected to conventional grid at bus 1.

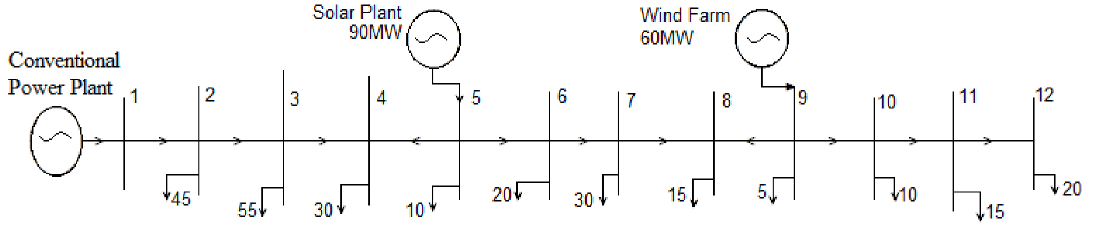

Fig. 4 : 12-bus radial system

The direction of power flow is also shown in figure 4. There is only one path between each generator and load pair which is the shortest path. If power flow does not follow shortest path then placement of controller may be decided to minimize distance which will lead to reduction of loss. If power flows through shortest path between each generator and load pair then suitable resource will be allocated to each load by optimizing the line capacity.

7. Conclusion

This paper presents an optimization based methodology to allocate suitable source to all individual loads present in interconnected microgrid network. GA is used to minimize the power loss in the system by identifying the shortest path while maximizing the use of lines near their load carrying capability; this is achieved by using an objective function that depends on distance. A source is allocated to every load present in the network which corresponds to shortest path. To make the achieved optimum result applicable to the system in reality, the system physical properties need to be analyzed to check if power can be forced through the system according to the optimal path. To accomplish this, the optimum path and power flow directions are compared to decide on number of controllers and their locations. Number of controllers that finally will be installed is decided by comparing the cost of controllers and cost associated with reduction in loss. Hence, the local microgrid operator will have the flexibility to choose between cost reductions in terms of power loss reduction by introducing controllers which again increases cost. The method is applicable for any type of microgrid configuration whether it is interconnected or radial topology.

Acknowledgement

This work is funded by SERB (DST), Government of India (Project No. ECR/2017/001027).

References

[1] Hossam A. Gabbar, Aboelsood Zidan, "Optimal scheduling of interconnected micro energy grids with multiple fuel options" *Sustainable Energy, Grids and Networks (Elsevier)*, Vol.7, pp. 80-89, 2016.

[2] Christof Deckmyn *et. al.*, "A microgrid multilayer control concept for optimal power scheduling and voltage control" *IEEE Trans. Smart Grid*, Vol. 99, DOI: 10.1109/TSG.2017.2658865, Jan 2017.

[3] M. Stadler *et. al.*, "Control of greenhouse gas emissions by optimal DER technology investment and energy management in zero-net-energy buildings" *Eur. Trans. Elect. Power*, vol. 21, no. 2, pp. 1291-1309, 2011.

[4] S. G. M. Rokni, M. Radmehr, A. Zakariazadeh, "Optimal energy resource scheduling in a microgrid using a distributed algorithm framework" *Sustainable Cities and Society (Elsevier)*, Vol. 37, pp. 222-231, 2018.

[5] A. Anvari-Moghaddam *et. al.*, "Efficient energy management for a grid-tied residential microgrid" *IET Generation Transmission and Distribution*, vol. 11, no. 11, pp. 2752-2761, 2017.

[6] M. Khan, *et. al.*, "Peak load scheduling in smart grid communication environment" *Proc. of Int. Conf. on Advanced Information Networking and Applications (AINA)*, pp. 1025–1032, 2014.

[7] I. Sharma, K. Bhattacharya, C. Canizares, "Smart distribution system operations with price-responsive and controllable loads" *IEEE Trans. Smart Grid*, Vol. 6, Iss. 2, pp. 795–807, 2015.

[8] Jingrui Zhang *et. al.*, "A hybrid harmony search algorithm with differential evolution for day-ahead scheduling problem of a microgrid with consideration of power flow constraints" *Applied Energy (Elsevier)*, Vol. 183, pp. 791–804, 2016.

[9] Hung-Lin Chao, Pao-Ann Hsiung, "A fair energy resource allocation strategy for micro grid" *Microprocessors and Microsystems (Elsevier)*, Vol. 42, pp. 235–244, 2016.

[10] K.H.S.V.S. Nunna, S. Dolla, "Demand response in smart distribution system with multiple microgrids" *IEEE Trans. Smart Grid*, Vol. 3, Iss. 4, pp. 1641-1649, 2012.

[11] K.H.S.V.S. Nunna, S. Dolla, "Responsive end-user-based demand side management in multimicrogrid environment" *IEEE Trans. Industrial Informatics*, Vol. 10, Iss. 2, pp. 1262-1272, 2014.

[12] K.H.S.V.S. Nunna *et. al.*, "Multi-agent based demand response management system for combined operation of smart microgrids" *Sustainable Energy, Grids and Networks (Elsevier)*, Vol. 6, pp. 25-34, 2016.

[13] D. E. Olivares *et. al.*, "Trends in microgrid control," *IEEE Trans. Smart Grid*, vol. 5, no. 4, pp. 1905–1919, July 2014.

[14] N. Karoda, M. K. Mishra, "Grid adaptive power management strategy for an integrated microgrid with hybrid energy storage" *IEEE Trans. on Industrial Electronics*, vol. 64, no. 4, April 2017.

[15] M. N. Naz *et. al.*, “Multicriteria decision making for resource management in renewable energy assisted microgrids” *Renewable and Sustainable Energy Reviews (Elsevier)*, http://dx.doi.org/10.1016/j.rser.2016.12.059, 2016.

[16] M. Nemati, M. Barun, S.Tenbohlen, “Optimization of unit commitment and economic dispatch in microgrids based on genetic algorithm and mixed integer linear programming” *Applied Energy (Elsevier)*, Vol. 210, pp. 944-963, 2018.

[17] Z. Liu, *et. al.,* “Energy storage capacity optimization for autonomy microgrid considering CHP and EV scheduling” *Applied Energy (Elsevier)*, Vol. 210, pp. 1113-1125, 2018.

[18] M. G. M. Abdolrasol *et. al.*, “Virtual power plant and microgrids controller for energy management based on optimization techniques” *Journal of Electrical Systems,* Vol. 13, No. 2, pp. 285-294, 2017.

[19] Vaiju Kalkhambkar *et. al.*, “Optimal allocation of renewable energy sources for energy loss minimization” *Journal of Electrical Systems,* Vol. 113, No. 1, pp. 115-130, 2017.

[20] S. Hussain, Ali Al Alili, A. M. Al Qubaisi, “Optimization based fuzzy resource allocation framework for smart grid” *IEEE Int. Conf. on Smart Energy Grid Engg. (SEGE)*, 2015.

[21] Tarek AlSkaif, Manel Guerrero Zapata, Boris Bellalta, “A Reputation-Based Centralized Energy Allocation Mechanism for Microgrids” *IEEE Int. Conf. on Smart Grid Communications (SmartGridComm): Architectures, Control & Operation for Smart Grids & Microgrids*, 2015.

[22] Qianwen Xu *et. al.,* “A Decentralized Dynamic Power Sharing Strategy for Hybrid Energy Storage System in Autonomous DC Microgrid” *IEEE transactions on industrial electronics*, Vol. 99, Sep 2016.

[23] A. G. Azar, *et. al.*,: “A Greedy Agent Based Resource Allocation in the Smart Electricity Markets” AIAI, *IFIP (International Federation for Information Processing)*, pp. 150–161, 2014.

[24] J. H. Neher, M. H. McGrath: “The calculation of the temperature rise and load capability of cable systems” *AIEE transactions*, vol. 76, part III, pp. 752-764, Oct. 1957