Available online at www.sciencedirect.com
ScienceDirect
Procedia Computer Science 89 (2016) 412 – 421
Procedia Computer Science

Twelfth International Multi-Conference on Information Processing-2016 (IMCIP-2016)

A Novel Architecture for Data Management and Control in Autonomous Intelligent Microgrid

R. Hari Kumar* and S. Ushakumari

College of Engineering Trivandrum, Thiruvananthapuram, Kerala, India

Abstract

Intelligent microgrid with distributed energy sources is considered as the next generation grid to mitigate the present day power system issues. Intelligent microgrid should facilitate monitoring and distributed control of the system using smart components. For effective, reliable and intelligent operation of such a system, it needs to use the advanced communication and intelligent information processing techniques. This paper explores the possibility of managing an autonomous intelligent microgrid with prioritized loads, utilizing the existing communication networks to acquire data and manage from a central location. The central control center runs an energy management algorithm, utilizing the load and source data acquired from the clients, to maximize the power delivery to the higher priority loads. The proposed scheme enables the consumers to dynamically set their load priority and fix the rate for selling the power generated by them within the autonomous grid, thereby ensuring consumer participation in the development of power infrastructure. Further, a load management algorithm for the reliable operation of autonomous intelligent microgrid with prioritized loads is proposed and its effectiveness is illustrated with a case study.

Peer-review under responsibility of organizing committee of the Organizing Committee of IMCIP-2016

Keywords: Autonomous Microgrid; Data Acquisition; Data Management; Intelligent Control; Prioritized Load Management.

1. Introduction

Conventional electric power system consists of three basic components; the generating station, the transmission system and the distribution system. In this scheme, large quantum of energy is generated at generating stations located far away from the load center using fossil fuels, nuclear and hydro sources. This energy is exported to the distribution system through the transmission lines which connects the generating stations and the distribution systems. Further, the distribution system feeds the individual loads in a locality.

With the ever increasing population, the per capita energy consumption has increased drastically, which demands increased power generation. In addition, power quality, reliability, environmental concerns and energy efficiency are the major issues to be confronted in the present-day power system. It is extremely difficult to address these issues with the existing infrastructure and can be achieved only by investing a significant amount for its upgradation. An alternative to meet these requirements in the deregulated power system scenario is to integrate small scale, modular and highly efficient DGs in the distribution system. Various distributed generation technologies, which are usually located in the

*Corresponding author. Tel.: +91-944-670-7870.
E-mail address: harikumar.cet@gmail.com

Peer-review under responsibility of organizing committee of the Organizing Committee of IMCIP-2016
doi:10.1016/j.procs.2016.06.089

consumer sites include, photovoltaics, wind turbines, fuel cells, micro-turbines and diesel generators. If the DGs are properly planned, there will be reduction in distribution losses, improvement in the voltage profile and reliability of the system. However, these DGs can cause as many problems as it may solve[1]. Hence, a better way to extract maximum benefits from DG and manage network safely and efficiently is to develop a system approach which considers a collection of generators and loads as a subsystem, called microgrid[2].

Nomenclature

IMG	Intelligent Microgrid
DG	Distributed Generator
DCM	Data Collection Module
CDLCM	Client Data Logging and Control Module
CMCM	Central Management and Control Module
ANN	Artificial Neural Network
MLP	Multilayer Perception
ICT	Information and Communications Technology

In microgrid perspective, the consumers are more demanding and the performance indicators are not only voltage, reactive power and load, but also the priority of load, reliability, cost, emissions and the revenue from the distributed generators installed at their premises. These additional considerations increase the complexity of the design and operation of microgrid than that of the conventional distribution system. This demands the development of a novel architecture for data management and control to ensure stable and reliable operation of microgrid, with prioritized loads, in autonomous mode. Such an infrastructure must have intelligent distributed and centralized controllers to mitigate the power imbalance between generation and demand. Further, it must have robust operating capability with plug-and-play features, wherein new sources and loads can be added to the existing system without any topology changes. Moreover, there must be algorithms for optimal management, and operation based on customer requirements. Such increased visibility and control of generation and demand in IMG will enable the utility to promote the integration of renewable based distributed generation, with increased grid reliability and security. The illustration of an autonomous intelligent microgrid is shown in Fig. 1.

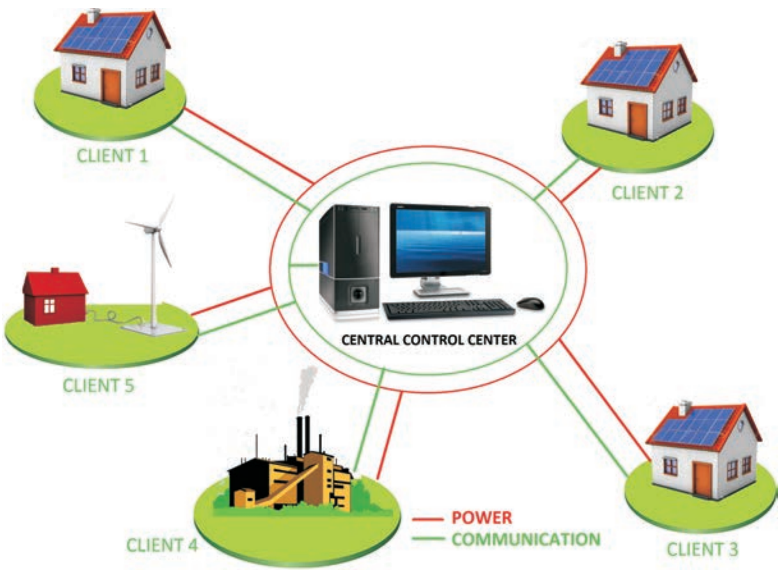

Fig. 1. Autonomous Intelligent Microgrid.

In literature several approaches have been reported for the intelligent energy management in microgrid[3–5]. Potty *et al.* proposes a microgrid model for community based energy harvesting and sharing of power[6]. Hierarchical agent based management of smart microgrid to handle dynamic demand and distributed energy resource is proposed by Jiang *et al.*[7] Online energy management of a microgrid with the objective of cost and emission minimization has been investigated by Chaouachi *et al.* The optimal scheduling of battery energy storage system and the uncertainty of various exogenous variables and the forecasted parameters in the microgrid are considered for management[8]. A vehicle-to-grid mobile energy network model for demand management using electric vehicle is proposed by Yu *et al.*[9] The opportunity for utilities to optimize industrial demand response in order to minimize peak energy demand on the existing AC distribution system, by a load shifting demand side management technique based on time of day tariff is investigated by Kinhekar *et al.*[10] From literature it can be seen that opportunity for the customer to interactively participate in intelligent microgrid and smart grid operation is minimum. Further, the management of loads in autonomous microgrid, with priorities set on chronological order is not seen addressed in literature. Moreover, to stimulate the large scale development of autonomous microgrid, a cost effective architecture for data management and control having increased visibility and decision making capability is inevitable.

The primary focus of this work is to develop an IMG architecture, which can operate in real time, without human intervention, by data management and control, exploiting the advancements in communication and information processing. This architecture aims to have a positive impact on the daily life of customers coming under the intelligent microgrid umbrella, by enabling them to set and perform higher priority activities that require electricity, on a daily basis. The proposed system is capable of monitoring, understanding and managing the power imbalances in the microgrid, with the added feature of consumer involvement in power trading within small grids.

In this paper, Section 2 introduces the proposed system architecture for data management and control, Section 3 elaborates the real time management of intelligent microgrid with typical case study and Section 4 summarizes the features and benefits of the proposed architecture.

2. System Architecture

The architecture for real time management of an intelligent microgrid is as shown in Fig. 2. The primary building blocks of such a system are:

- A data collection module to collect client data.
- A data logging and control module for storing the client data and taking local control actions.
- A communication framework
- A central management and control module to collect data from all the clients and take appropriate decisions.

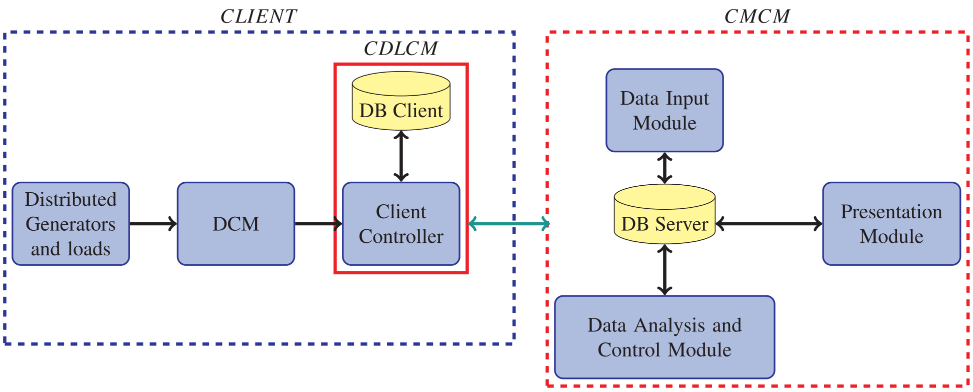

Fig. 2. Architecture for Real Time Management of an Intelligent Microgrid.

2.1 Data collection module

The DCM is the fundamental component of IMG, which collects real time data from various components of the microgrid. It consists of sensors, analog to digital converter and a processor. The sensor converts the monitored voltage and current from the load and generation points, and the status of the controllable switches in the system to a measurable electrical signal. The analog to digital converter converters the continuous physical parameters to a digital number equivalent to its amplitude and a processor computes other system parameters such as phase angle, power, energy and harmonics from the measured voltage and current data for further storage and analysis.

The data collected by the DCM are required to understand the present status of the system and for management and control in real time. Hence the data needs to be acquired in a timely and accurate form. One of the major problem associated with the collection of data from the components which are distributed in the grid is lack of information regarding the time at which data is acquired and the delay in transmitting data from the point of acquisition to a central location where the decisions are taken. This will avert the central controller from getting a globally consistent view of the system and demands time stamping of the monitored data before being sent to the central location. Hence, a GPS-based system is used for time stamping the monitored data.

2.2 Client data logging and control module

The realization of IMG operation demands high performance, modular, low cost infrastructure which is capable to store the data temporarily and take control decisions locally. In recent years, there has been considerable development in the low-power, open-hardware computers. Such sophisticated computers can operate independently or can be networked and has enough memory and other capabilities to make real-time data logging and control a cost effective solution. The CDLCM is an open-hardware computer, which can function as the distributed controller in the proposed architecture. The basic functions of this module are:

- time stamp and record the data at regular intervals. The data include, voltage, current, power, energy, dc power generated by renewable sources and status of controllable switches.
- take necessary control actions, without any human intervention, based on the signals from the central controller. This includes connecting and/or disconnecting the loads based on power availability and controlling the generation based on demand.

The CDLCM has digital and analog input/output channels which enables data acquisition and controlling of components in the system. The module is also equipped with software program for data logging and control. In addition, CDLCM has a database to store the time stamped data. This is to ensure zero data loss while transferring data to a central location for processing. In order to increase the reliability of the microgrid, ICTs need to be integrated into the system. The CDLCM communicates with all the peripheral devices through a communication medium, which may be wired, Zigbee, Wi-Fi, WIMAX, chosen depending on the location of the consumers.

2.3 Communication framework

For implementing the proposed architecture, existing communication system and protocols can be made use of. The communication protocols mainly used in the power sector are: Modbus, DNP3, IEC-60870-5-101/104 and IEC 61850.

2.4 Central management and control module

The CMCM performs the collective monitoring and control of various components in microgrid. The cardinal element of the CMCM is a server or a host computer with a database and applications to communicate with the CDLCM, local data base and the external world. The CMCM is designed to have the following capabilities:

- administer the communication with CDLCM.
- store the data received from the CDLCM.

- determine the optimal load that can be supplied based on available generation and performs the centralized real time control.
- facilitate an interface to support the functionalities to achieve plug-and-play feature of the loads and sources.

The components of CMCM are data input module, database server, data analysis and control module and data presentation module.

2.4.1 Data input module

The data for microgrid management comes from the CDLCM installed at the consumer locations and by manual input from the users. The data manually entered by the users are load priority and expected rate for selling the energy produced by the consumers having generation capability in their premises. The data from the CDLCM is retrieved and stored in the database server using an automated system.

2.4.2 Database sever

The server or the host computer has a database which records the real time data collected from all the CDLCM in the network and the data keyed in by the user.

2.4.3 Data analysis and control module

In the power system network, the power variations are very rapid and unpredictable. Further, in autonomous microgrid interfaced with renewable sources, there will be large variation in the energy generated due to the intermittent nature of the renewable sources. Hence, to alleviate the power mismatch, time stamped generation and load data retrieved from all the clients at frequent intervals are used to optimize the generation and load in the system. This function is performed by a real-time processing and control module in the server.

2.4.4 Data presentation Module

The web based human-machine-interface act as the data presentation layer. This layer provides the user with energy consumption pattern, power, voltage and current profiles, which is extracted or processed from the raw data in the database. Hence, there is better visibility on the power consumption pattern and the usage of energy by the consumers. Further, future trends of the power demand and generation can be visualized through this layer which will enable the prosumers to fix the optimum rate for the energy produced by them.

3. Real-Time Management of Intelligent Autonomous Microgrid

The inputs required for real time management of microgrid are the data from each client, the load priority and the rate for the energy produced by the consumers from on-site generators. The client data is obtained from the database in CDLCM installed at each consumer premises through the communication channel. In order to achieve a cost effective solution, an open hardware computer which has limited storage is used as the CDLCM. Hence, the data in the CDLCM database is deleted immediately after it is retrieved and stored in the database server.

The load priority is specified by the consumers through a web interface and can be modified as and when required. This is necessary because the priority of performing various tasks will vary from consumer-to-consumer and on a day-to-day basis. In the present scenario, the consumers have only limited privilege to set the load priority. Hence, in the proposed architecture, the consumers are given privilege to set and modify their load priority, and the load management is based on the set priority.

Further, the expected tariff for the power sold can be set on an hourly basis, through a web based interface, by the consumers having DG at their premises (prosumer). When the consumer installs a DG, in addition to reliability improvement, he expects the pay back on the investment in shortest possible time. A novel concept for promoting the DG installation and consumer involvement in autonomous microgrid development is proposed in this work. When the generation in the system is less and only the first priority loads are active in the system, the rate charged to the consumers will be based on the tariff set by the individual prosumer. Further, optimization can be done to fix the tariff, and generation set point when the generation is more than demand.

One of the main issues associated with the autonomous operation of microgrid is to devise a strategy for real time management, which ensures stable and reliable operation of the system. This demands real time control to balance the generation and demand. Further, the visualization of the various parameters in the system and the trend forecasting will empower the consumers to maximize benefits from the system through energy trading within the autonomous microgrid.

3.1 Energy balance management

In this section, load management algorithm to ensure energy balance in IMG is proposed. It is assumed that each consumer in the IMG is installed with DCM and CDLCM. Further, this study assumes that controllable breakers are provided to connect/disconnect the loads based on the available generation. The control signals are provided from the CDLCM, based on the decision from the CMCM. The bidirectional communication between CDLCM and CMCM is through an existing communication channel. The aim of this strategy is to serve maximum higher priority loads in the system. This scheme provides an economical and feasible architecture for the autonomous operation of microgrid.

```
Input: Generation, load magnitude, load priority
Output: Updated status of load breakers
Determine amount of mismatch between generation and demand.
Prepare a load aggregate table based on priority.
Determine the index in the load aggregate table having aggregate less than or equal to the magnitude of load to
be switched off.
if (Index exists) then
    if (aggregate < load to be switched off) then
        Index=Index+1
    end if
else
    Index=1
end if
Determine the priority of the load corresponding to the index.
Switch off the loads having priority less than the obtained priority.
Determine the no. of loads having priority equal to the obtained priority
if (no. of loads > 1) then
    Use discrete PSO to identify the optimum load to be switched off
else
    Switch off the corresponding load
end if
```

Algorithm 1. Algorithm for Priority based Load Management

For real-time energy balancing, three types of data are required: the load data, the generation data and the load priority data. In IMG, generally the loads will be given priority in chronological order. Moreover, multiple loads with different magnitudes may have the same priority and this need to be considered. Hence the objective function for load management is defined as[11]:

$$\text{Maximize } f(x) = \sum_{i=1}^{N_{\text{Load}}} x_{Li}\ \text{Load}_i \tag{1}$$

$$\text{Subject to } \sum_{i=1}^{N_{\text{Gen}}} x_{Gi} P_{Gi} \geq \sum_{i=1}^{N_{\text{Load}}} x_{Li}\ \text{Load}_i \tag{2}$$

where N_{Load} is the number of loads, N_{Gen} is the number of generators, x_{Li} is the breaker status for i^{th} load, Load_i is the magnitude of the i^{th} load, x_{Gi} is the breaker status for i^{th} generator and P_{Gi} is the power generation of the i^{th} generator in the system.

The CMCM continuously checks for the power mismatch between generation and demand. In the event of a power mismatch, load and generation data together with the priority of each load is given as input to the load management algorithm 1, which determines the optimum amount of load that can be supplied based on the available generation.

Case study

To demonstrate the performance of the proposed algorithm, consider the IMG with 5 residential consumers, each having 5 loads and 2 kW renewable based DG installed at their site. In addition, energy storage is provided to support the momentary fluctuations in demand. The proposed load management is based on the power available from the DG.

The various loads under consideration for the residential consumers are : refrigeration - 150 W, cooking - 500 W, lighting - 200 W, air conditioning (AC) - 1000 W and others - 150 W. Each load is set with different priority by the consumer itself through the web interface and is given in Table 1. From Table 1 it can be seen that the consumers can set same priority for different loads.

In case study, it is assumed that the generation from DG has reduced to 8 kW and the demand is 10 kW. Hence there is a need for switching off 2 kW load in the system. Once the mismatch is identified, a load aggregate table is

Table 1. Load Priority of Consumers.

Consumer 1 (C1)		Consumer 2 (C2)		Consumer 3 (C3)		Consumer 4 (C4)		Consumer 5 (C5)	
Load	Priority	Load	Priority	Load	Priority	Load	Priority	Load	Priority
Refrigeration	1	Cooking	1	Lighting	1	Cooking	1	Lighting	1
Cooking	2	Refrigeration	2	Cooking	2	Lighting	2	AC	2
Lighting	2	Lighting	2	AC	3	Refrigeration	3	Cooking	3
AC	3	AC	3	Refrigeration	4	AC	4	Refrigeration	3
Others	4	Others	3	Others	5	Others	4	Others	4

Table 2. Load Aggregate Table.

Index	Load (Consumer)	Priority	Magnitude (W)	Load Aggregate(W)
1	Others (C3)	5	150	150
2	Others (C5)	4	150	300
3	Others (C4)	4	150	450
4	AC (C4)	4	1000	1450
5	Refrigeration (C3)	4	150	1600
6	Others (C1)	4	150	1750
7	Refrigeration (C5)	3	150	1900
8	Cooking (C5)	3	500	2400
9	Refrigeration (C4)	3	150	2550
10	AC (C3)	3	1000	3550
11	Others (C2)	3	150	3700
12	AC (C2)	3	1000	4700
13	AC (C1)	3	1000	5700
14	AC (C5)	2	1000	6700
15	Lighting (C4)	2	200	6900
16	Cooking (C3)	2	500	7400
17	Lighting (C2)	2	200	7600
18	Refrigeration (C2)	2	150	7750
19	Lighting (C1)	2	200	7950
20	Cooking (C1)	2	500	8450
21	Lighting (C5)	1	200	8610
22	Cooking (C4)	1	500	9150
23	Lighting (C3)	1	200	9350
24	Cooking (C2)	1	500	9850
25	Refrigeration (C1)	1	150	10000

prepared by the algorithm as in Table 2. Further, the algorithm checks for the index in the load aggregate table having aggregate less than or equal to 2 kW. The corresponding index from load aggregate table is 7 and the corresponding load is having priority 3. As this aggregate value is less than 2 kW, index is updated by one. Hence the new index is 8 and the corresponding load is having priority 3. Immediately all the loads having priority 4 and 5 are switched off, leaving a mismatch of 250 kW. Further as there are 7 loads with the priority 3, PSO based optimization algorithm is executed to find the minimum load to be switched off. This leads to switching off “refrigeration” of consumer 5 and loads coming under “others” of consumer 2. Further, it can be noted that each load coming under same priority is having equal probability of being switched off which is the advantage of this algorithm.

3.2 Parameter visualization

As the real-time data is available in the database server, it is possible to visualize the various electrical parameters of the system. This preview of data enables the consumers to have improved planning in their energy utilization. The presentation layer has a web interface, which ensures that the data is presented in a more meaningful format. The sample screenshot of the parameter visualization window is shown in Fig. 3.

3.3 Future trend forecasting

The major source of energy in the autonomous IMG is solar or wind. Due to the unpredictability of the output from these sources, it is necessary to predict the output to ensure reliable operation of the system. Further, with the real time data available in the database, the future demand trend can also be projected.

ANN is widely used in the forecasting of various parameters in power system[12]. The power of ANNs lies in its ability to prevent the auto-correlative relations in a time series even in situations where the laws are unknown or too complex to define. As quantitative forecasting is based on deriving patterns from observed past events and extrapolating them into the future, ANN is preferred for the task. In this work, MLP, which is the most widely used ANN architecture is

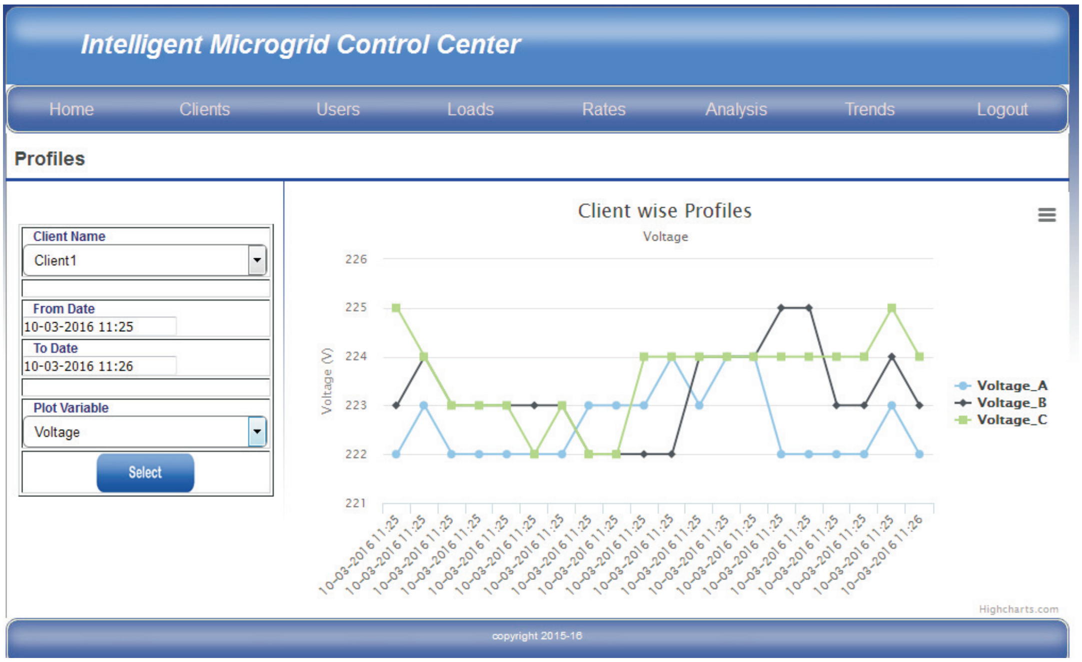

Fig. 3. Web Interface for Visualzing Historical Trends of Parameters.

Sl. No.	From Time	To Time	Rate
1	00:00:00	00:59:59	5.00
2	01:00:00	01:59:59	5.00
3	02:00:00	02:59:59	5.00
4	03:00:00	03:59:59	5.00
5	04:00:00	04:59:59	5.00
6	05:00:00	05:59:59	5.00
7	06:00:00	06:59:59	8.00
8	07:00:00	07:59:59	8.00
9	08:00:00	08:59:59	8.00
10	09:00:00	09:59:59	7.00
11	10:00:00	10:59:59	7.00
12	11:00:00	11:59:59	7.00

Fig. 4. Web Interface for Entering the Expected Rate of Energy by Prosumers.

used for future trend forecasting. Root mean square error and mean absolute error are the measures used to indicate the forecasting accuracy and are found to be less than 0.02.

3.4 Energy trading

Even though energy trading is an area which is being researched in large power system scenario, a simple concept of energy trading within the IMG, which is expected to stimulate the consumer participation in generation and optimum utilization of energy, is presented in this paper. Each consumer can specify the hourly rate at which power can be sold to the grid through a web interface as shown in Fig. 4. For this, he can use the forecast of generation and demand provided by the presentation layer. The rate specified by the prosumers will be considered only when the grid is feeding the first priority loads with generation less than demand.

4. Conclusions and Scope for Further Research

ICT assisted schemes is employed in this work for the effective management of autonomous microgrid. This is made possible by adding sensors, use of communication facility and efficient data management, thereby making microgrid intelligent. In this paper, a high performance, modular, low cost, data acquisition and management infrastructure which is capable of effectively managing the autonomous microgrid is proposed. The advantage of the proposed scheme is that, it facilitates plug-and-play features of sources and loads. Moreover, the consumers can dynamically choose their load priority and the complete management of the system is based on the set priority. A sample case study is presented to demonstrate the effectiveness of this feature.

The visualization of various parameters in the system and trend forecasting is the added feature of this work, which will empower the consumers to reap maximum benefits from the system. This will assist the prosumers to set optimum price for energy produced and participate in energy trading within the autonomous microgrid, enabling them to recover the investment on DG within a short period. The proposed IMG architecture can be setup in industrial parks, campuses, commercial and residential buildings.

The future work aims to investigate the effectiveness of the various communication protocols that can be used for this system and to suggest the best option.

References

[1] R. H. Lasseter and P. Paigi, Microgrid: A Conceptual Solution, In *Proceedings of IEEE 35th Annual Power Electronics Specialists Conference, PESC 04*, vol. 6, pp. 4285-4290, (2004).

[2] R. H. Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle and R. Guttromson *et al.*, White Paper on Integration of Distributed Energy Resources, The CERTS Microgrid Concept. Tech. Rep.; Consortium for Electric Reliability Technology Solutions, California Energy Commission, (2002).

[3] S. X. Chen and H. B. Gooi, Jump and Shift Method for Multi-objective Optimization, *IEEE Transactions on Industrial Electronics*, vol. 58(10), pp. 4538-4548, (2011).

[4] S. Paudyal, C. A. Canizares and K. Bhattacharya, Optimal Operation of Distribution Feeders in Smart Grids, *IEEE Transactions on Industrial Electronics*, vol. 58(10), pp. 4495-4503, (2011).

[5] H. Kanchev, D. Lu, F. Colas, V. Lazarov and B. Francois, Energy Management and Operational Planning of a Microgrid with a PV-based Active Generator for Smart Grid Applications, *IEEE Transactions on Industrial Electronics*, vol. 58(10), pp. 4583-4592, (2011).

[6] K. A. Potty, P. Keny and C. Nagarajan, An Intelligent Microgrid with Distributed Generation, In *Proceedings of IEEE International Conference on Innovative Smart Grid Technologies – Asia (ISGT Asia)*, pp. 1-5, (2013).

[7] B. Jiang and Y. Fei, Smart Home in Smart Microgrid: A Cost-Effective Energy Ecosystem with Intelligent Hierarchical Agents, *IEEE Transactions on Smart Grid*, vol. 6(1), pp. 3-13, (2015).

[8] A. Chaouachi, R. M. Kamel, R. Andoulsi and K. Nagasaka, Multiobjective Intelligent Energy Management for a Microgrid, *IEEE Transactions on Industrial Electronics*, vol. 60(4), pp. 1688-1699, (2013).

[9] R. Yu, W. Zhong, S. Xie, C. Yuen, S. Gjessing and Y. Zhang, Balancing Power Demand through EV Mobility in Vehicle-to-grid Mobile Energy Networks, *IEEE Transactions on Industrial Informatics*, vol. 12(1), pp. 79-90, (2016).

[10] N. Kinhekar, N. P. Padhy, F. Li and H. O. Gupta, Utility Oriented Demand Side Management using Smart AC and Micro DC Grid Cooperative, *IEEE Transactions on Power Systems*, vol. 31(2), pp. 1151-1160, (2016).

[11] R. H. Kumar and S. Ushakumari, Optimal Management of Islanded Microgrid using Binary Particle Swarm Optimization, In *Proceedings of IEEE International Conference on Advances in Green Energy*, pp. 251-257, (2014).

[12] N. Mayadevi, S. Ushakumari and S. S. Vinodchandra, SCADA-based Operator Support System for Power Plant Equipment Fault Forecasting, *Journal of the Institution of Engineers (India): Series B*, vol. 95(4), pp. 369-376, (2014).