Research Journal of Applied Sciences, Engineering and Technology 7(1): 91-96, 2014
DOI:10.19026/rjaset.7.225
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 29, 2013 Accepted: March 02, 2013 Published: January 01, 2014

Research Article

Integration of Distributed Energy Resources

[1]Pushpendra Singh, [2]D.P. Kothari and [1]Mool Singh
[1]Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur
[2]Director General, JB Group of Educational Institutions, Hyderabad and Former Director I/C IIT Delhi

Abstract: This Study proposes the feasibility of proposed restructured power system for the integration of distributed energy resources. Once the proposed power system network takes place, it will be able to provide opportunities for sustained economic growth. Main objectives of the proposed network are maximization of Distributed Generation (DGs) penetration and decarbonization of electric utility. IEEE-14 bus test system with proposed configuration has been undertaken for MATLAB® Simulations, results shows that proposed power system configuration allows the operation of conventional energy generation and green energy generation efficiently. The results obtained from MATLAB® simulations are compared with genetic algorithm based optimization approach.

Keywords: Distributed Generators (DGs), distribution networks, Genetic Algorithm (GA), green energy sources, smart grid

INTRODUCTION

Electricity is essential for the social and economic development of a nation. The electric energy demand is growing continuously with the increase of population and changing life styles. There is need to meet the increased energy demand without affecting the reliability and continuity of supply (Papathanassiou, 2007). The increased energy demand can be met by:

- Generating the more energy from remotely located centralized power plants.
- Reduce the distribution network losses.
- Reducing the electricity demand considerably by using energy efficient electric appliances.
- By generating the electric energy at consumer end (at their home/premises) by installing the solar panels and small wind generators (Lopes *et al*., 2007).

In order to meet the increased energy demand the power generation capacity has to be increased with more environmental constraints. There is need to generate the electricity from green energy sources for the reduction of green house gas emissions and dependence on fossil fuels (Hamedani Golshan and Arefifar, 2006; Amin and Wollenberg, 2005). Presently, electricity is being generated at remotely located centralized generating stations, which is being transferred through the transmission and distribution networks at specified voltage and frequency. The transmission networks are designed smartly and operate in well intelligent manner (Hamedani Golshan and Arefifar, 2006). However, the distribution networks are designed only for unidirectional flow of power. Integration of distributed generators with the distribution networks the power may flow in opposite direction too (Lopes *et al*., 2007). The distribution networks are not designed to integrate distributed generators, storage devices and electric vehicles etc. as the existing system is vertically integrated. Green energy sources may be suitable to meet-out the electricity demand locally (Jiyuan and Stuart, 2009). There is need to operate the distributed generators in coordination with utility grid to ensure the reliability and enhanced power capacity and quality (Celli *et al*., 2005). In order to meet the increased energy demand there is urgent need to reduce the distribution network losses and increase the penetration of distributed generators. The distributed generators may operate with the old fashioned designed distribution networks, but at the same time the power quality adversely be affected (Hadjsaid *et al*., 1999). The availability of green energy sources is basically found in distributed manner and power generation is intermittent in nature (Papathanassiou, 2007). There is need of a new power system network configuration to accommodate the higher capacity of distributed energy resources which provide affordable, clean and reliable power to the consumers and also reduce the green house gas emissions (Hamedani Golshan and Arefifar, 2006).

This study analyzes the feasibility of proposed power system configuration with the help of MATLAB®/Simulation and using GA approach, which

Corresponding Author: Pushpendra Singh, Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur

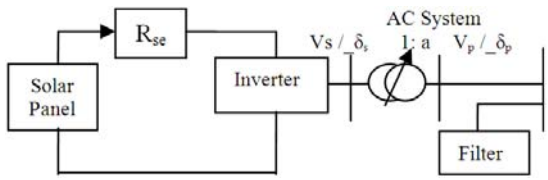

Fig. 1: Grid tied/ off-grid solar system

allow the integration of distributed generators, energy storage devices and supply the power to the consumers efficiently.

ELECTRICITY GENERATION FROM GREEN ENERGY SOURCES

In order to have a sustainable development the electricity generation should be sufficient to meet the electricity demand. There is an urgent need to meet the electricity demand with more environmental constraints and clean energy mechanism. The electricity can be produced with the green energy sources (i.e., mini/micro hydro plants, solar, wind and fuel cells etc.) as fossil fuel resources will not be available for much longer period. It has been estimated that by the year 2100 the electricity generation from green energy sources will be about 80 percent of total electric energy generation (Kothari *et al*., 2011). The green energy technologies considered in this study are mini/micro hydro plants, wind and solar energy resources to generate electricity. The preferred electric system control approach will always place those distributed generating units in high loading order, which means those units will tend to be loaded first and operated whenever the resources are available to displace the power produced by units using conventional fuels (Ali, 2008).

Solar energy: Sun is a free energy source which is not only naturally renewable but also environment friendly**.** The solar radiation received on the surface of the earth on a bright sunny day at noon is about 1 kW/m^2. The daily global radiation is around 5 kWh/m^2/day with sun shine ranging between 2300 and 3000 h/year (Kothari *et al*., 2011).

$$P = I_o A \cos\theta \text{ kW}$$
$$P/A = I_o \cos\theta \text{ kW/m}^2$$

As shown in Fig. 1 the solar panels may be tied with the utility grid through inverter and transformer. Accommodation of solar energy with the utility grid will be helpful to make the power system more effective because of inverter may control the active power, reactive power or combination of both as per requirement (Pushpendra *et al*., 2012).

Wind energy: Wind is a commercially and operationally the most viable green energy resource. The power available in the wind flowing over the earth surface has estimated to be about 1.6×10^7 MW. This is more than the present energy demand of the world. Currently wind provides approximately 1% of the world's electricity and the amount of installed capacity is continuously increasing. The key factors that affect the integrated operation of modern electrical systems are:

- The low energy density of wind
- The fluctuating nature of energy generation
- The non-dispatch ability of wind generation (Kothari *et al*., 2011):

$$P_{wind} = 1/2\, \rho\, A\, V^3 \text{ Watts}$$

Substituting an average value of wind density:

$$\rho = 1.225 \text{ kg/m}^3; \qquad P/A = 1/2\, \rho\, V^3 \text{ Watts/m}^2$$

Variable electricity generation from green energy sources rely on resources that fluctuate over the time period and do not have integrated storage capacity with the electric grid. Output from such plants fluctuates upwards and downwards according to the resource: the wind, cloud cover etc. Output of green energy sources does not drop from full power to zero or vice versa, but rather increases and decreases on a gradient as weather systems alter. Increased intermittent electricity generation leads to an additional burden in terms of balancing demand and supply (Lopes *et al*., 2007). If the output of green energy sources varies during minimum demand periods, the utility may have to decrease the electricity generation of base load generating plants to integrate all variable energy sources (Thomas, 2008). The intermittent generations produce electricity during peak load periods, they can displace more expensive power plants and their value will be higher. However, the output of green energy sources is subject to natural conditions, over which utilities have no control (Savier and Das, 2007; Papathanassiou, 2007).

Genetic algorithm: A global optimization technique known as genetic algorithm has emerged as a candidate due to its flexibility and efficiency for many optimization applications. Genetic algorithm is a stochastic searching algorithm. It combines an artificial, i.e., the Darwinian survival of the fittest principle with genetic operation, abstracted from nature to form a robust mechanism that is very effective at finding optimal solutions to complex-real world problems (Fatma *et al*., 2011; Mougharbel *et al*., 2010). Evolutionary computing is an adaptive search technique based on the principles of genetics and natural selection (Kothari and Dhillon, 2011). They operate on string structures. The string is a combination of binary digits representing a coding of the control parameters for a given problem. Many such string structures are considered simultaneously, with the most fit of these structures receiving exponentially increasing opportunities to pass on genetically important material to successive generation of string structures (Wong *et al*., 2011; Gulcihan and Bagriyanik, 2010). In this way, genetic algorithms search for many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The basic elements of genetic algorithms are reproduction, crossover and mutation (Shengyou *et al*., 2012; Kothari and Dhillon, 2011). An algorithm of the described process is presented below:

i. Code the problem variables into binary strings
ii. Randomly generate initial population strings.
iii. Evaluate fitness values of population members.
iv. Is solution available among the population? If 'yes' then go to step (ix)
v. Select highly fit strings as parents and produce off springs according to their fitness.
vi. Create new strings by mating current offspring. Apply crossover and mutation operators to introduce variations and form new strings.
vii. New strings replace existing one.
viii. Go to step (iv) and repeat.
ix. Stop.

Smart grid: As the concept of Smart Grid utility is yet to stabilize, it has different connotations to different users at different times. The differences generally are with regard to the quantity of accruing benefits of this new technology and the priority it deserves. As of now the concept of Smart Grid provides merely the basic structure that envisages new ideas and innovative systems of efficacious power generation and delivery (Pipattanasomporn, 2009; Brown, 2008).

The archaic system of energy system and delivery devised a century ago will not be compatible with the new concept because it was designed to suit a centralized and controlled electricity generation mechanism with remotely located generation plants in less prohibitive environmental checks to support overbuild and accommodate load growth (Amin and Wollenberg, 2005). Presently however far more radical and challenging strategies are called for to ensure reliable operations taking care of voltage profile, un-expected fluctuations and outages, harmonic disturbances and host of social and political issues (Saint, 2009). This has become necessary as the consumers are increasingly becoming sensitive to their rights and expectations especially in the context of fast paced economic scenario (Brown, 2008). Energy is now required to run highly sophisticated and sensitive gadgets and machines for various individual, social and industrial uses. Besides the new technology has also to contend with environmental constraints putting a cap on emission levels and infrastructural overbuilds (Ali, 2008). The existing infrastructure and utilities encounter various limitations of designs in loading and life cycles. The new crop of power engineers find it increasingly difficult to cope with the system and are opting out, underscoring the need for complete overhaul of present methods and usher in new technologies (Savier and Das, 2007). Smart Grid envisages bold new systems marking a complete shift from the past. It opts for more open and consumer friendly cultures, doing away with restrictive and monopolized markets and controlled operations (Cagil *et al*., 2007). As against large and remote generation plants, Smart Grid recognizes the need for small, distributed, renewable energy options (i.e., mini/micro hydro, wind, solar and fuel cell power etc.), so that power can be efficiently and directly controlled and new systems are devised to take in to account consumer responses, load variations and price fixation (Jiyuan and Stuart, 2009; Pipattanasomporn, 2009).

PROBLEM FORMULATION

The objectives of proposed power system configuration is to allow the integrated operation of green energy sources with distribution networks towards making green economy and empowerment of the consumers. The R/X ratio of distribution networks is higher as compared to transmission networks, as a result the voltage regulation and network losses considerably affected.

The present power system has been reconfigured as shown in Fig. 2 to meet out the proposed objectives. In normal practice the inner ring is considered as infinite bus where the voltage and angle specified as $1/0^0$. The outer ring of proposed designed system has been considered as infinite bus. Thus, all the power system components operate according to the proposed power system configuration. The proposed power system for increased integration of green energy sources are formulated as below:

$$\mathrm{Min}\ P_{Losses} = \sum P_{gi} - \sum P_{Demand}$$

$$\mathrm{Min}\ P_{G\,conv.} = \sum P_{gi} - \sum P_{gGreen}$$

Subject to:

- The energy balance equation:

$$\sum_{i=1}^{NG} Pgi = \sum_{i=1}^{NB} Pdi + PL$$

$$\sum_{i=1}^{NG} Qgi = \sum_{i=1}^{NB} Qdi + QL$$

- The inequality constraints:

Table 1: Simulation results of various network configurations

Network configurations		Electricity generation from fossil fuel based centralized power plants (MW)	T&D Network Losses (MW)	CO_2 emission in kilotons
Simulation results of 14-bus system		272.40	13.400	266.952
Simulation results of 25-bus system and distribution network (radial)	Without DGs	336.70	77.700	329.966
	With 10% DGs	325.40	66.400	318.892
	With 20% DGs	314.12	55.120	307.838
	With 30% DGs	304.70	46.820	298.606
	With 40% DGs	293.60	34.600	287.728
	With 50% DGs	279.70	20.700	274.106
	With 60% DGs	269.60	10.600	264.208
Simulation result of 44-bus system and distribution interconnected network	Without DGs	386.70	127.70	378.966
	With 10% DGs	338.97	115.97	332.192
	With 20% DGs	279.71	84.710	274.116
	With 30% DGs	236.52	67.520	231.789
	With 40% DGs	179.43	40.430	175.841
	With 50% DGs	131.55	24.550	128.919
	With 60% DGs	95.530	10.530	93.4234

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max}$$

$$Q_{\tau i}^{min} \le Q_{\tau i} \le Q_{\tau i}^{max}$$

$$V_i^{min} \le V_i \le V_i^{max}$$

Real power flow:

$$Pi\,(V, \delta) = Vi \sum_{j=1}^{NB} Vj(Gij \cos(\delta i - \delta j) + Bij \sin(\delta i - \delta j))$$

Reactive power flow:

$$Qi\,(V, \delta) = Vi \sum_{j=1}^{NB} Vj(Gij \sin(\delta i - \delta j) - Bij \cos(\delta i - \delta j))$$

where,
NB = The number of buses
NG = The number of generation buses
P_L = The T&D network real power loss
Q_L = The T&D network reactive power loss
Pi = The active power injection into bus i
Qi = The reactive power injection into bus i
Pdi = The active load on bus i
Qdi = The reactive load on bus i
Pgi = The active generation on bus i
Qgi = The reactive generation on bus i
Vi = The magnitude of voltage at bus i
Δi = The voltage phase angle at bus i
Yij = Gij+j Bij (are the elements of admittance matrix)

A fourteen bus system with centralized power generation having radial feeders in which power flows only in one direction from grid to consumers, has been modified according to the proposed configuration. If distributed generators are connected with the radial feeders, the electricity generations from primary energy sources get reduced and at the same time power quality of that feeder adversely be affected. The fourteen bus system has been simulated according to proposed approach, in which power may flow in both directions and utilize the electricity produced from distributed energy resources. This focuses especially on minimization of electricity generation from conventional power plants and also minimize additional power system infrastructure.

ENVIRONMENTAL IMPACT OF SYSTEM STUDIED

21st century has been witnessing serious threat to the progress of human civilization due to dearth of energy. As on date more than 90% of global energy requirements are fulfilled by burning of fossil fuels with the consequent release of harmful pollutants that impose serious warning to the environmental security for the future generations. An average carbon dioxide (CO_2) emission for electricity generation from coal based thermal power plant is approximately 0.98 kg of CO_2/kWh. This intensity factor is modified by multiplying with factor 1.5 which accounts for 30% loss of energy in transmission and distribution and 20% of loss due to the use of inefficient electric equipments at power plants in India. Hence, the revised intensity factor for CO_2 emissions in India is 1.47 kg of CO_2/kWh of electrical energy generation from coal based thermal power plants (Chel *et al*., 2009). With new proposed system configuration large amount of CO_2 emission get reduced as shown in Table 2.

RESULTS OF PROPOSED POWER SYSTEM CONFIGURATION

The increased penetration of DGs in electrical power networks may cause a considerable mismatch between electricity demand and supply at any point in the distribution network. This happens due to the irregular energy generation from solar and wind generators. The mismatch may also due to the use of

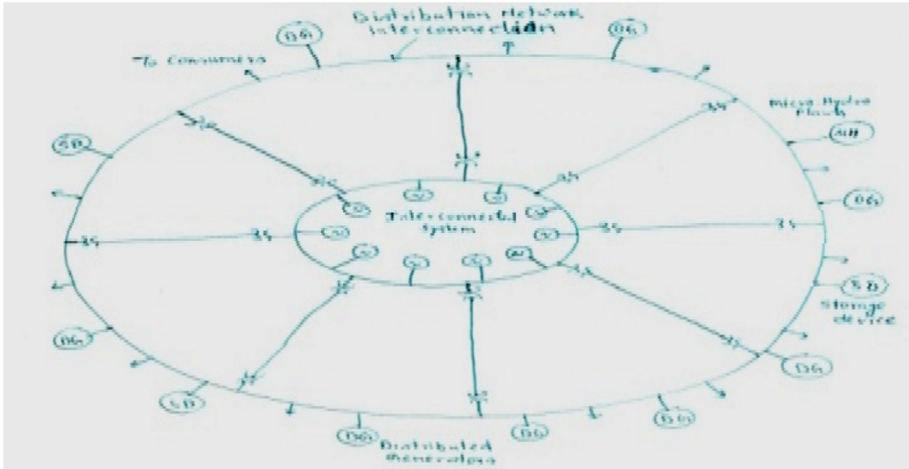

Fig. 2: Proposed power system configuration

Table 2: Test system results with proposed configuration

Network configuration		Simulation results: Electricity generation from conventional power Plants (MW)	Simulation results: T&D network Losses (MW)	Simulation results: Voltage in p.u.	Results from GA approach: Electricity generation from conventional power Plants (MW)	Results from GA approach: T&D network Losses (MW)	Results from GA approach: Voltage in p.u.
IEEE-14 bus system		272.40	13.40	Min. voltage = 1.010 (3) & Max. voltage = 1.09 p.u. (8)	270.16	11.16	Min. voltage = 1.009 p.u. (3) & Max. voltage = 1.091 p.u. (8)
25-Bus system with radial feeders	Without DGs	336.70	77.70	Min. voltage = 0.853 (20) & Max. voltage = 1.09 p.u. (8)	331.37	72.37	Min. voltage = 0.841 p.u. (22) & Max voltage = 1.079 p.u. (1)
	With 10% DGs	325.40	66.40	Min. voltage = 0.859 (16) & Max. voltage = 1.091 p.u. (8)	327.15	68.15	Min. voltage = 0.850 p.u. (17) & Max. voltage = 1.089 p.u. (8)
	With 20% DGs	314.12	55.12	Min. voltage = 0.925 (16) & Max. voltage = 1.096 p.u. (8)	308.63	49.63	Min. voltage = 0.921 p.u. (16) & Max. voltage =1.110 p.u. (8)
	With 30% DGs	304.70	46.82	Min. voltage = 0.969 (24) & Max. voltage = 1.096 p.u. (8)	301.86	42.86	Min. voltage = 0.955 p.u. (28) & Max. voltage =1.110 p.u. (8)
	With 40% DGs	293.60	34.60	Min. voltage = 1.003 (15) & Max. voltage = 1.129 p.u. (8)	290.19	31.19	Min. voltage = 1.005 p.u. (16) & Max. voltage = 1.089 p.u. (8)
	With 50% DGs	279.70	20.70	Min. voltage = 1.012 (3) & Max. voltage = 1.152 p.u. (8)	284.33	25.33	Min. voltage = 1.008 p.u. (3) & Max. voltage = 1.179 p.u. (8)
	With 60% DGs	269.60	10.60	Min. voltage = 1.014 (4) & Max. voltage = 1.27 p.u. (22)	266.85	7.85	Min. voltage = 1.018 p.u. (1) & Max. voltage = 1.24 p.u. (23)
44-Bus system with proposed configuration	Without DGs	386.70	127.70	Min. voltage = 0.759 p.u. (25) & Max. voltage = 1.072 p.u. (8)	392.28	133.28	Min. voltage = 0.772 p.u. (22) & Max. voltage = 1.06 p.u. (8)
	With 10% DGs	338.97	115.97	Min. voltage = 0.778 p.u. (25) & Max. voltage = 1.070 p.u. (3)	334.67	111.28	Min. voltage = 0.782 p.u. (25) & Max. voltage = 1.072 p.u. (2)
	With 20% DGs	279.71	84.71	Min. voltage = 0.809 p.u. (25) & Max. voltage = 1.075 p.u. (2)	275.49	86.39	Min. voltage = 0.793 p.u. (25) & Max. voltage = 1.081 p.u. (2)
	With 30% DGs	236.52	67.52	Min. voltage = 0.853 p.u. (15) & Max. voltage = 1.065 p.u. (1)	239.07	69.14	Min. voltage = 0.862 p.u. (17) & Max. voltage = 1.072 p.u. (1)
	With 40% DGs	179.43	40.43	Min. voltage = 0.958 p.u. (44) & Max. voltage = 1.058 p.u. (1)	175.81	37.73	Min. voltage = 0.945 p.u. (41) & Max. voltage = 1.048 p.u. (3)
	With 50% DGs	131.55	24.55	Min. voltage = 0.991 p.u. (19) & Max. voltage = 1.09 p.u. (8)	128.07	22.51	Min. voltage = 0.988 p.u. (19) & Max. voltage = 1.062 p.u. (8)
	With 60% DGs	95.53	10.53	Min. voltage = 1 p.u. (17) & Max. voltage = 1.066 p.u. (1)	92.27	9.13	Min. voltage = 0.985 p.u. (4) & Max. voltage = 1.07 p.u. (25)

active loads, including the charging of Plug-In-Hybrid Electric Vehicles (PHEVs). The results obtained from the existing power system configuration and proposed power system configuration are shown in Table 1 with various level of penetration of distributed energy resources. The losses and electricity generation from centralized power plants with adoption of the proposed configurations as shown in Fig. 2, get reduced considerably. Table 2 also shows the comparison of Results obtained from MATLAB simulation and GA approach for finding the feasibility.

CONCLUSION

Since it is well known that DGs play a positive and beneficial role in power systems, they are integrated into the existing or future power system operation. The traditionally separated generation, transmission and distribution planning processes will not be adequate in the current changing environment. In this study, the integration strategies of DG in network reconfiguration for loss reduction and maximization of distributed energy resources penetration are presented. The proposed power system configuration allows the integration of distributed energy resources with the distribution networks. The interconnection of distributed generation to the existing distribution network poses enormous and inordinate technical challenges as potential technical issues arising from the incorporation of the DGs. The conventional power plants will continue to play an active role to handle the intermittency of electricity generation and also stabilize the grid operation. The proposed configuration with the help of MATLAB simulation and GA based approach, showing the integrated operation of power system has reduced distribution network losses, electricity generation from conventional power plants and also green house gas emissions. The new power system configuration will not only boost the green house gas emission mitigating efforts but also empower the consumers to produce electricity by installing solar panels and small wind generators for their use and if excess electricity is generated, it may be stored in the batteries of electric vehicles or sell back to the utility at competitive cost. This study shows the viability of the proposed power system configuration using MATLAB simulation and also using GA approach.

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