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Research Article

Interconnected Distribution Networks for Climate Change Abatement

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Abstract: This study proposes introduction of advanced power system configuration for enhancing the efficacy of clean energy mechanism and to ensure reduction in adverse impact on climate. There is increasing scientific evidence showing that burning of fossil fuels are altering the earth's climate, because combustion of fossil fuels produces green house gases. This can be countered by increasing the share of renewables in the total electricity generation, which can effectively reverse adverse impact on climate change consequents. The deployment of renewable energy sources has become necessary to promote the sustainability of energy and environment, this call for the deployment of renewable energy sources at large scale and injecting the electricity generated from the renewable energy sources in to the grid. The existing power system configuration was designed for centralized electricity generation, with limited capacity for reversing power and is not equipped to extract the full potential of renewables. There is need to evolve a distribution system configuration that will interact with distributed energy resources and load demands. The proposed network configuration has been simulated using MATLAB/simulink.

Keywords: Climate change, distribution networks, renewable energy sources, smart grid

INTRODUCTION

Electricity is essential for the development of nations around the world. The electricity demand is growing continuously with 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
- Reducing the transmission/distribution network losses
- Reducing the electricity demand considerably by using energy efficient electric appliances
- By generating the electric energy at consumer ends from distributed generators and by installing the solar panels and small wind generators (at their home/premises) (Lopes *et al*., 2007)

Conventionally, electric energy is produced by conversion from fossil fuels (i.e., coal, oil, natural gas), nuclear and hydro sources. The earth has fixed non-replenish-able resources of fossil fuels and nuclear materials (Kothari *et al*., 2011). Most of the fossil fuel reserves at the projected consumption rates, technologist already see the end of the earth's non-replenish-able fuel resources. In recent years, concerns have been growing worldwide regarding the environmental consequences of heavy dependence on fossil fuels. There is an urgent need to generate power from renewable energy sources at or near to the consumer ends (Lopes *et al*., 2007). The main drawbacks of renewable energy sources are the availability in dispersed and intermittent nature of electricity generation. The benefits of electricity production from renewable energy production are no air pollution, no green house gas emissions, availability benefits in rural areas etc. However, integration of these technologies in the electricity system has become a challenge for utility around the world (Hadjsaid *et al*., 1999; Celli *et al*., 2005). In order to minimize the environmental problem there is need to generate the power from green energy sources (Pushpendra *et al*., 2012). In present power system configuration, power generated at remotely located centralized plants is being transferred to the consumers through the transmission and distribution networks at specified voltage and frequency. The transmission network is designed smartly and operates in well intelligent manner, but the distribution networks are designed only for unidirectional flow of power (Golshan and Arefifar, 2006). The availability of green energy sources is basically found in distributed manner and also electricity generation from renewable energy sources is intermittent in nature. The existing distribution network configuration is not designed for the integration of

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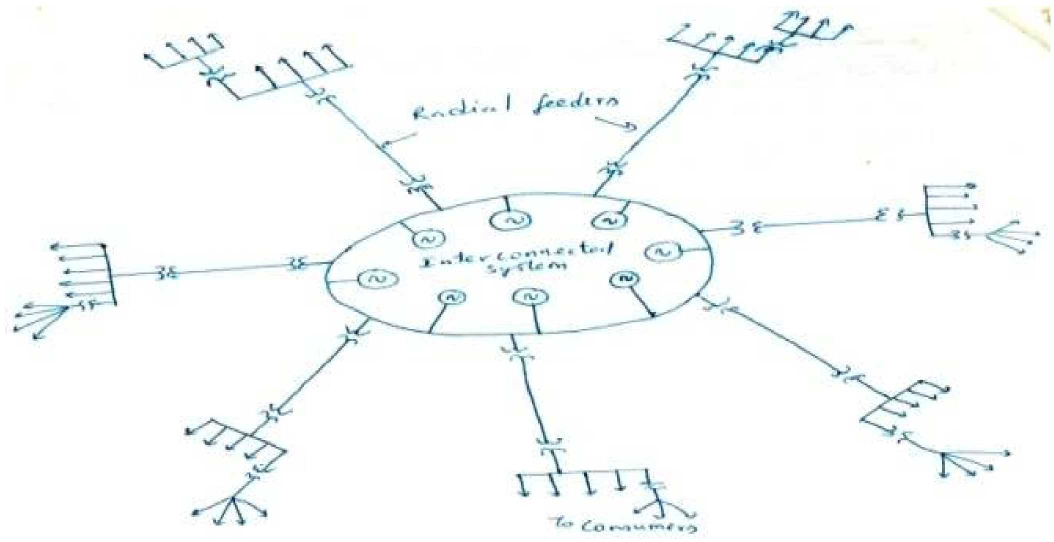

Fig. 1: Present power system configuration

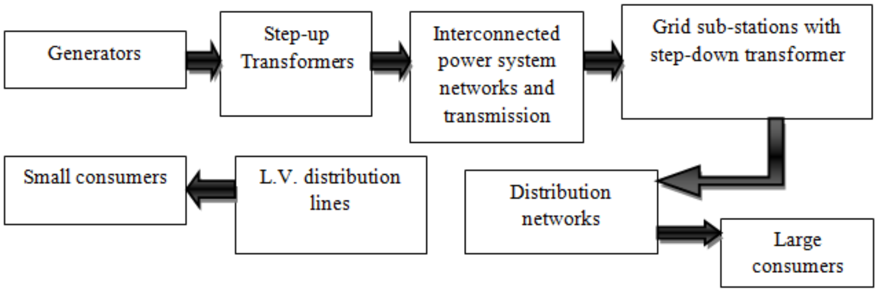

Fig. 2: Existing power system configuration

distributed generators, storage devices and electric vehicles etc., (Savier and Das, 2007; Gautam and Mithulananthan, 2007).

In order to achieve the reduction of green house gas emissions, electricity must be generated from green energy sources at large scale. This results the reduction in electricity generation from fossil fuel based power plants. The existing old fashioned grid configuration has to be reconfigured for extracting the full potential of renewables. For managing the grid operation in such environment smart grid has to be implemented along with the power system reconfiguration.

MODERN POWER SYSTEM CONFIGURATION

Power system traditionally designed for vertically integrated structure, in which electricity is generated at remotely located centralized power plants as in Fig. 1. These power plants are mainly located close to the availability of energy resources. The generated electrical energy is transferred to the dispersed end-users by a hierarchical configuration of High-Voltage (HV) transmission networks and Medium-Voltage (MV) and Low-Voltage (LV) distribution networks, as shown in (Fig. 2) in the existing system configuration, the electrical power flows from the higher to the lower voltage levels (Kothari and Nagrath, 2003).

Vertically integrated structure of the power system have many advantages i.e., economic operation of power plants, reduction in required reserve capacity of the power plants, higher energy efficiency in large generating units and operation with a relatively small crew. Instead of these advantages, conventional power generation bears natural drawbacks. These drawbacks are basically of socioeconomic and environmental constraints that overcome during recent years, by with the development of non-conventional power generation scheme and distributed energy resources (Gautam and Mithulananthan, 2007).

DISTRIBUTION NETWORK AND IMPACTS OF DGS

The main function of distribution networks is to transfer electricity to consumers after receiving electric energy from interconnected transmission networks. The electric energy is being transported from remotely located centralized power plants to the consumers. The

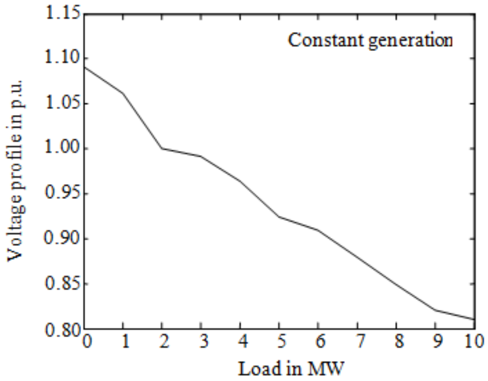

Fig. 3: Voltage profile at load bus of the radial network for constant generation

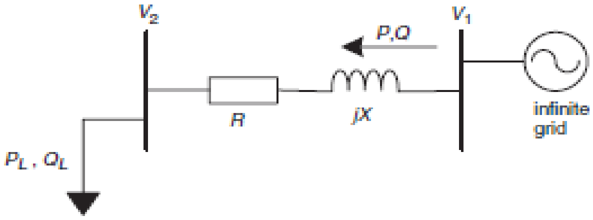

Fig. 4: Basic two bus-bar (radial) network

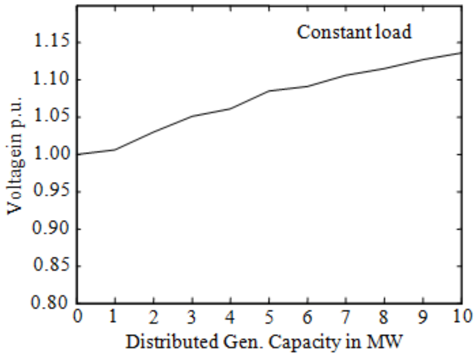

Fig. 5: Load bus voltage profile of the radial network with injected generator power and constant load

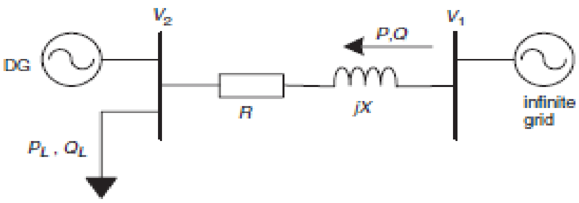

Fig. 6: Voltage profile of the radial network with distributed generators

transmission system of an area is known as a grid. The different grids are interconnected through tie-lines to form a national grid and the different regional grids are also interconnected to form a national grid. Each grid operates independently (Jiyuan and Bolas, 2009). However, power can be transmitted from one grid to another during sudden loss of generation or increase in load. Distribution networks are designed to supply power to meet out the load demands at a specified voltage level, if load increased on distribution line the voltage at the bus may not be in the specified limit as in (Fig. 3). The existing distribution network having distributed generators as in (Fig. 4), the voltage rise problem has been observed as in (Fig. 5).

Distribution feeders are typically operated in a radial fashion. Feeders consist in a tree-like topology rooted at the secondary of a transformer, typically with on-load tap-changing for voltage regulation (Lopes *et al*., 2007).

The voltage at bus-bar 2 calculated as:

$$V_2 \approx V_1 + R(P_G - P_L) + X(Q_G - Q_L)$$

The voltage profile at bus (2) varying with the capacity of distributed generators at the end of radial feeders as shown in (Fig. 6) (Masters, 2002). When DG capacity is higher than the connected load at that particular node the direction of power flow be in opposite direction, the power quality of supply gets affected as in (Fig. 5) (Brown, 2008). The benefits which we can get from distributed generators in relation to transmission and distribution networks could include reduction in additional power system infrastructure; transmission and distribution network losses, improved reliability and quality, improved voltage regulation, transmission and distribution system congestion. The integration of distributed generators with distribution network could worsen the performance of the power system (Amin and Wallenberg, 2005). For example, the reliability of the power system may be degraded if the distributed generators are not properly coordinated with the electric power system protection. The integration of distributed generators can have a serious impact on the operation and integrity of the electric power (Jiyuan and Borlase, 2009; Pipattanasomporn *et al*., 2009).

Integration of distributed energy resources: The existing way of electricity production and utilization is not sustainable. The electricity is being generated primarily from fossil fuel (coal, gas and oil etc.) based centralized power plants. The fossil fuel sources are finite natural resources and depleting at a faster rate. The fossil fuel reserves are needed to preserve for longer period (Liew and Strbac, 2002). For energy security and climate change abatement, renewable energy sources are only the way (Kothari *et al*., 2011). In the present scenario, there is need to generate more electricity from renewable energy sources i.e., small combustion turbines and micro turbines, small steam turbines, fuel cells, mini/micro hydroelectric power, photovoltaic, solar energy, wind turbines, energy storage technologies etc. Electricity produced from renewable energy sources need to be injected into the electric grid (Golshan and Arefifar, 2006; Thomos, 2008).

Existing Power system faces many problems when distributed generation is added with the distribution networks; this is because the power system was designed for electricity generation from centralized electricity generation. The addition of generation possibly will influence power quality problems, reduced system reliability due to electricity generation variability, reduction in the efficiency and over voltages issues (Masters, 2002). On the other hand the power system distribution are well designed which could handle the addition of generation if the power system configuration modified similar to the existing interconnected transmission network configuration, which could facilitate the integration of new generation (Dondi *et al*., 2002). Modern electric power system configurations interconnect centralized power plants through high voltage transmission networks and provide electricity to the consumers through radial feeders. With the increasing efforts towards electricity generation from green energy sources, there is need to integrate the distributed energy resources with the power system, which may be modified for the integration of dispersed electricity generation (Celli *et al*., 2005).

Future power system: The electricity generation is responsible for about 40% and transportation sector about 35% approximately towards carbon dioxide emissions that cause global warming and climate change. There is an urgent need to use energy efficient electric appliances and to produce electricity from green energy sources at small consumer level to large power plants. Electricity generation from green energy sources will reduce reliance on conventional fuel based power plants. Electricity production from green energy sources transmission and distribution network losses, power system infrastructure requirements and green house gas emissions get reduced (Dondi *et al*., 2002). The existing grid configuration has been designed for vertical integration of centralized power plants. For the integration of renewable energy sources with the grid, power system configuration has to be modified towards horizontal configuration, which will integrate the distributed energy produced from renewable energy sources locally (Panagis *et al*., 2007).

For the efficient utilization of available capacity of distributed energy resources, all the distributed generators must be interconnected. With the interconnection of distributed generators the variation in electricity generation from renewable energy sources is minimized. The interconnection of distributed generators will be similar to the existing interconnection of large capacity power plants which are connected with high voltage transmission networks. Similarly, the distributed energy resources will be interconnected with the low voltage networks because of lower capacity electricity generation (Radibratovic *et al*., 2007). The interconnection of distributed generators has urgent need of advanced power system configuration. The key elements of the new power system architecture are micro grids and a number of interconnectors.

Advanced Network reconfiguration is proposed for reducing the losses and increased integration of distributed energy resources as in Fig. 7. Because of impacts of DGs on power system operation, distributed generation has become one of the relevant parameters in the evaluation of system reconfiguration. On the other hand, the idea of distribution network interconnection has been introduced to meet out the future energy demands by integrating distributed generators (Bopp *et al*., 2003).

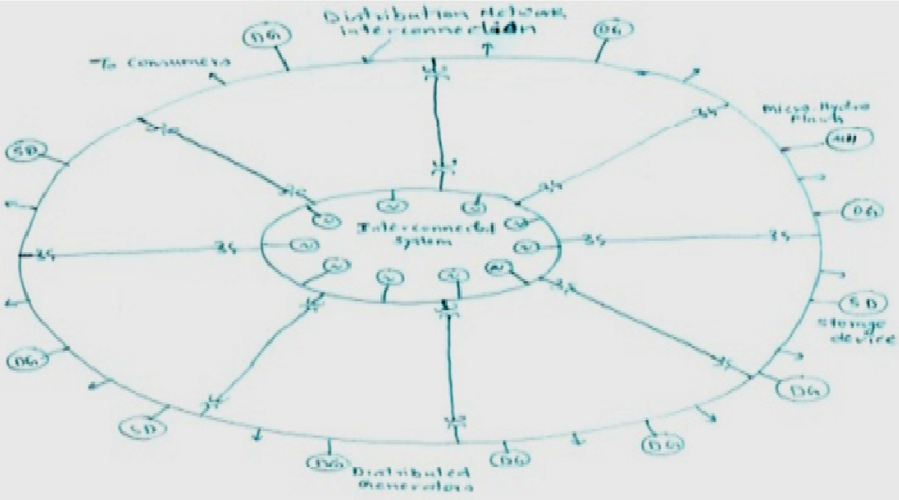

Fig. 7: Proposed power system configuration

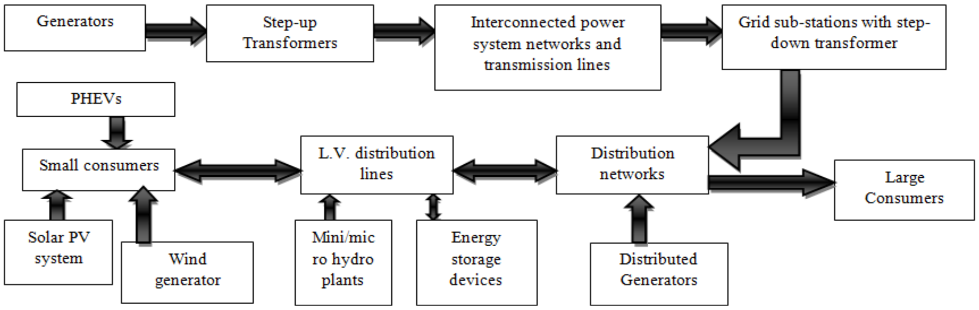

Fig. 8: Future power system configuration

The evolution of power system configuration allowing for increasing distribution automation, automated load controls and greater facilitation of features for improved power quality and reliability. These features are the part of a proposed power system configuration that is more reliable and for the integration of widespread distributed energy resources (Radibratovic *et al*., 2007).

The proposed interconnection of distribution networks similar to the existing transmission network, which will be able to integrate the local generators similar to existing interconnected transmission networks have large capacity generators connected to a common bus and supply the power to the consumers through the transmission and distribution networks as in Fig. 8.

The applications of advanced sensors, modern communication techniques, real time computation techniques and controllers will transform the present grid in to a future grid with the following abilities:

- Active participation of the customers
- Integrate distributed energy resources and storage devices
- Improve the power quality
- Utilize the resources efficiently

The future power system will be more reliable, secure, economical, efficient, safer and more environmental friendly as compared with the existing power system infrastructure.

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 (Thomas, 2008). 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 *et al*., 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 business mechanism with remotely located generation plants in less prohibitive environmental checks to support overbuild and accommodate load growth (Amin and Wallenberg, 2005). Presently however far more radical and challenging strategies are called for to ensure reliable operations taking care of low voltage, 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 (Vojdani, 2008). The existing infrastructure and utilities encounter various limitations of designs in loading and life cycles, so much so that 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 (Ozansoy *et al*., 2007). As against large and remote generation plants Smart Grid recognizes the need of small distributed generators so that power can be efficiently and directly controlled and new systems are devised to take in to account consumer responses (Jiyuan and Borlase, 2009; Pipattanasomporn *et al*., 2009).

PROBLEM FORMULATION

The main objective of proposed power system configuration is to allow the distributed generators with distribution networks towards making sustainable electric future and empowerment of the consumers. The present power system has been redesigned to meet out the 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 will operate according to the proposed power system configuration. An IEEE-5 bus system with centralized power generation having radial feeders in which power flows only in one direction from grid to consumers has been considered. With the integration of distributed generators, electricity generation from primary energy sources will get reduce and simultaneously power quality of that feeder will adversely be affected. The five bus system has been simulated using MATLAB/simulink according to proposed design approach in which power may flow in both directions and utilize the more electricity produced from green energy sources. This focuses especially on minimization of electricity generation from conventional power plants and also minimize additional power system infrastructure requirements. The proposed power system for increased integration of green energy sources has been formulated as below:

$$Min\ P_L = \sum P_{gi} - \sum P_{Demand}$$

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

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:

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

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

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 : T 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)

$$P_L = \sum_{i=1}^{NB}\sum_{j=1}^{NB}\left[a_{ij}(P_iP_j + Q_iQ_j) + b_{ij}(Q_iP_j - P_iQ_j\right]$$

$$Q_L = \sum_{i=1}^{NB}\sum_{j=1}^{NB}\left[C_{ij}(P_iP_j + Q_iQ_j) + h_{ij}(Q_iP_j - P_iQ_j\right]$$

where,

$$a_{ij} = \frac{R_{ij}}{|V_i||V_j|}\cos(\delta_i - \delta_j)$$

$$b_{ij} = \frac{R_{ij}}{|V_i||V_j|}\sin(\delta_i - \delta_j)$$

$$c_{ij} = \frac{X_{ij}}{|V_i||V_j|}\cos(\delta_i - \delta_j)$$

$$h_{ij} = \frac{X_{ij}}{|V_i||V_j|}\sin(\delta_i - \delta_j)$$

$$P_i = P_{gi} - P_{di}$$

$$Q_i = Q_{gi} - Q_{di}$$

P_i and P_j :The real power injection at i^{th} and j^{th} bus
Q_i and Q_j:The reactive power injection at i^{th} and j^{th} bus

SIMULATION RESULTS

The IEEE 5-bus system has been considered for showing the suitability of the proposed power system configuration for maximizing the electricity injection from distributed energy resources in to the grid while maintain the power quality. The IEEE 5-bus system is shown in (Fig. 9), bus 1 is the swing bus, bus 2 is PV bus while bus 3, 5 are reactive power installation buses.

Table 1: Transmission line parameters of 5-bus system

Line	Line parameters	Capacitive susceptance (½ B)
1-2	0.02+j 0.06	0.030
1-3	0.08+j 0.24	0.025
2-3	0.06+j 0.18	0.020
2-4	0.06+j 0.18	0.020
2-5	0.04+j 0.12	0.015
3-4	0.01+j 0.03	0.010
4-5	0.08+j 0.24	0.025

Table 2: Distribution line parameter

Line impedance per km. aluminum overhead line of 50 mm^2
(0.73 + j 0.38) ohm

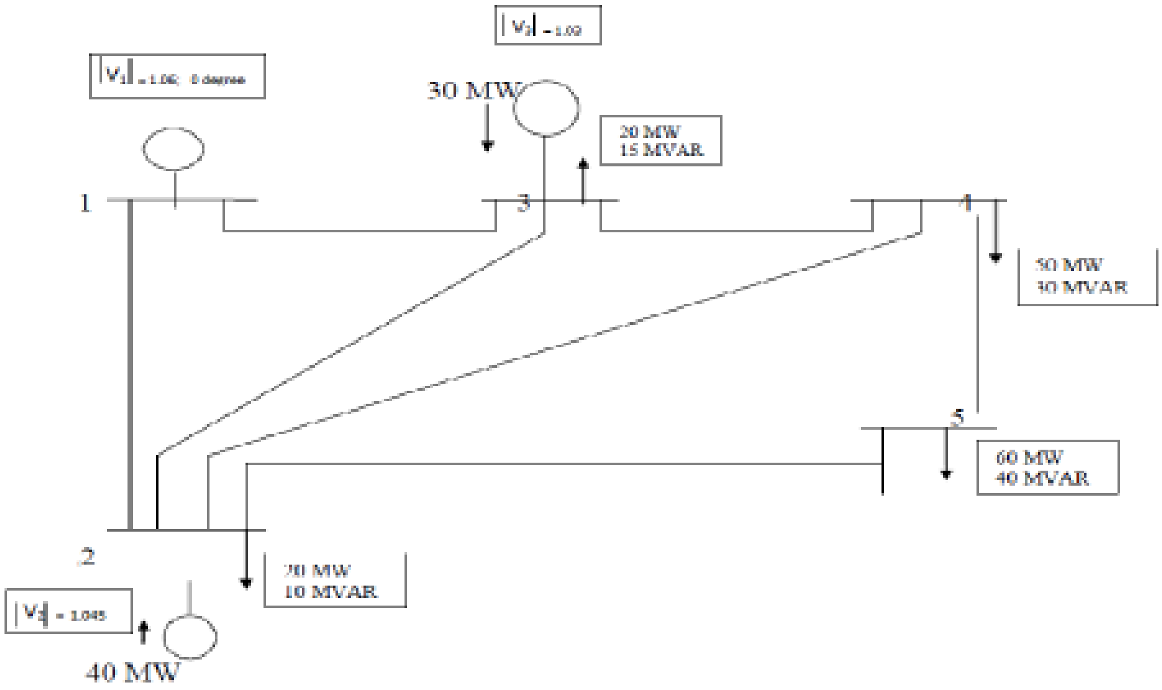

Fig. 9: 5-bus test system

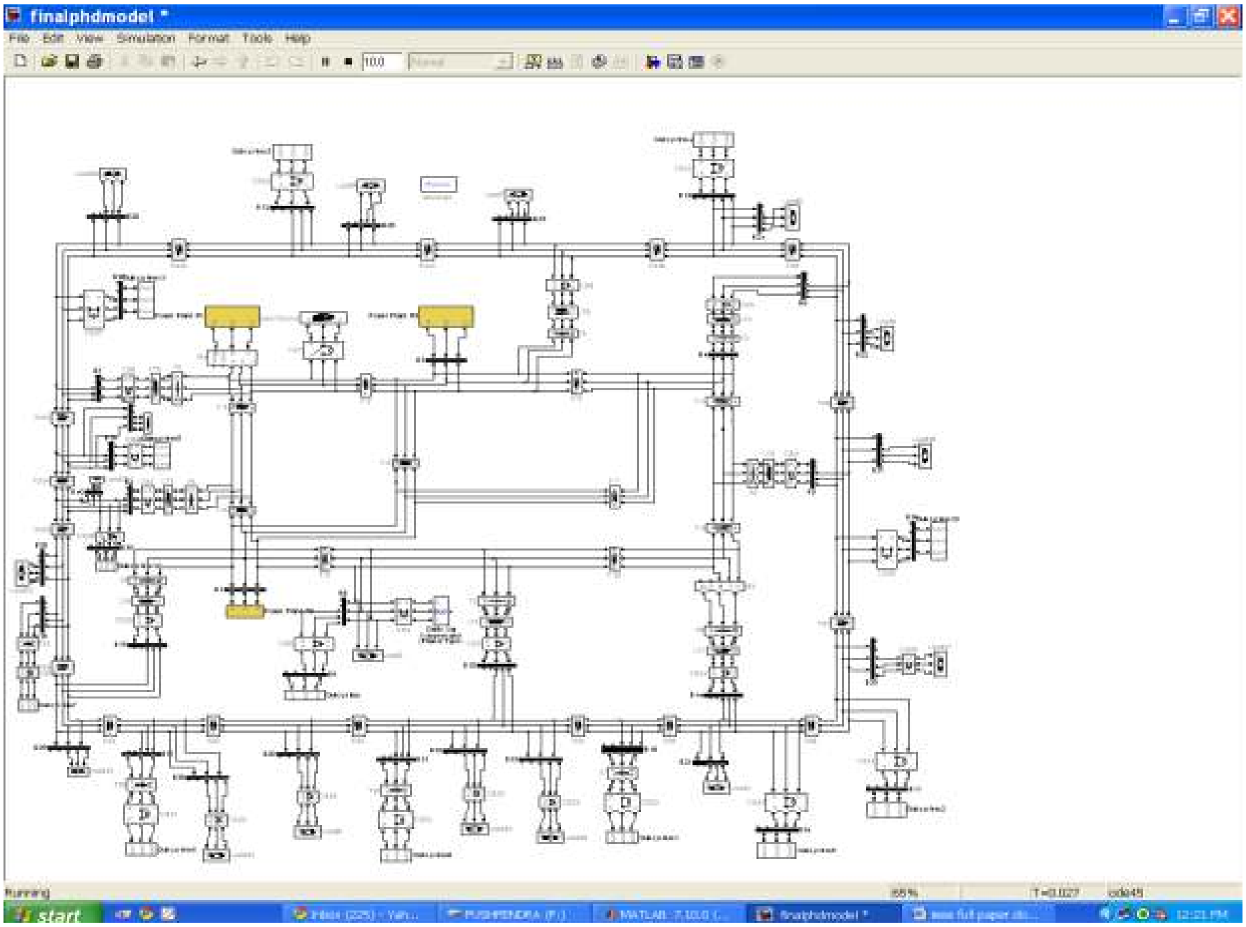

Fig. 10: Screen shot of test system

Table 3: Simulation of 10-bus system with 5-radial feeders and distributed generators

	Load		Generation/no penetration of DGs			Generation/10% penetration of DGs			Generation/20% penetration of DGs			Generation/30% penetration of DGs			Generation/40% penetration of DGs			Generation/50% penetration of DGs			Generation/60% penetration of DGs		
Bus no.	P_L	Q_L	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage
1	11.2	7.20	143.8	46.041	1.080	130.34	59.8	1.075	124.2	54.7	1.052	109.3	48.1	1.047	91.7	31.7	1.035	76.4	23.3	1.026	61.1	11.7	1.013
2	27.2	11.8	40.0	41.811	1.070	33.60	23.1	1.061	25.4	12.7	1.033	21.2	10.4	1.015	19.6	11.7	1.010	15.9	7.8	1.007	13.3	6.2	1.005
3	26.4	17.5	30.0	24.148	1.055	28.30	13.7	1.057	21.7	12.3	1.043	20.2	11.1	1.021	18.3	10.2	1.014	15.1	7.2	1.010	12.5	5.1	1.008
4	65.3	32.3	0.0	0.000	1.010	0.00	0.0	1.013	0.0	0.0	1.017	0.0	0.0	1.011	0.00	0.0	1.010	0.0	0.0	1.008	0.0	0.0	1.007
5	78.7	43.2	0.0	0.000	1.015	0.00	0.0	1.017	0.0	0.0	1.015	0.0	0.0	1.010	0.00	0.0	1.015	0.0	0.0	1.011	0.0	0.0	1.008
6	60.0	40.0	0.0	0.000	0.823	5.00	3.3	0.876	10.0	6.8	1.038	15.0	8.6	1.103	10.0	5.7	1.088	20.0	12.3	1.165	20.0	11.2	1.184
7	50.0	30.0	0.0	0.000	0.865	3.00	1.2	0.883	8.0	5.2	1.055	8.0	4.6	1.061	15.0	8.6	1.072	15.0	8.4	1.128	20.0	11.8	1.100
8	20.0	15.0	0.0	0.000	0.880	3.00	1.1	0.905	5.0	2.7	1.046	10.0	5.2	1.097	12.0	6.8	1.090	15.0	7.3	1.185	20.0	11.7	1.193
9	10.0	6.0	0.0	0.000	0.890	1.00	0.4	0.923	3.0	1.3	1.062	3.0	1.3	1.093	12.0	6.7	1.096	15.0	8.7	1.180	16.0	10.3	1.240
10	20.0	10.0	0.0	0.000	0.835	4.00	2.3	0.912	6.0	2.8	1.049	12.0	7.4	1.081	15.0	8.5	1.095	15.0	8.5	1.155	20.0	12.1	1.160

Table 4: Network losses with distributed generator penetration

Lines	No DGs	10% DG	20% DG	30% DG	40% DG	50% DG	60% DG
1-2	0.82512	0.81023	0.80535	0.80052	0.78379	0.76745	0.74256
1-3	0.41510	0.40327	0.40150	0.38324	0.37285	0.36058	0.35275
2-3	0.53022	0.52104	0.50353	0.47215	0.44718	0.42175	0.40719
2-4	0.42518	0.40122	0.38447	0.35358	0.34185	0.32068	0.30842
2-5	0.43324	0.41743	0.38895	0.36725	0.35587	0.35320	0.33578
3-4	0.14205	0.14115	0.13656	0.11847	0.10673	0.09874	0.09851
4-5	0.28157	0.27053	0.25015	0.22416	0.20617	0.19123	0.18207
1-6	10.04303	9.43512	7.28423	6.85376	6.65718	5.82173	4.60725
2-7	14.18534	12.72403	9.89420	7.45743	6.80589	5.12328	4.42870
3-10	12.15002	9.63520	9.53174	8.92535	5.85721	4.37219	4.03178
4-9	8.24205	7.85423	7.34265	6.78382	6.40587	5.65212	4.20513
5-8	6.12708	5.62655	6.37667	5.96057	5.25941	3.91705	3.19986

The line parameters of IEEE-5 bus test system shown in Table 1 and distribution line parameters shown in Table 2. Table 3 to 6 present the simulation results of the tested system. Table 3 shows the simulation results of IEEE 5-bus system with five radial feeders of 10 nodes. The test system has been simulated with different penetration level of distributed generators. From the (Table 3) it has been observed that the voltage profile at the nodes get disturbed with increasing DGs integration. From simulation results it also has been observed that only up to 20% DGs penetration be possible in distribution networks for the satisfactory operation of power system. Table 4 shows that the network losses considerably reduce with the distributed generators penetration level. In Table 4 it has been shown that the network losses are higher when no distributed generator was incorporate with the distribution networks. Table 5 shows the simulation results of proposed power system configuration i.e., double ring configuration. The proposed system has been simulated with different levels of DGs penetration as in Fig. 10. The proposed configuration without distributed generators, the network losses are higher and the voltage profile also very poor. From the simulation results it has been observed that proposed system configuration be suitable when DGs penetration level is beyond 40% of the system capacity. From the Table 5 it has also been observed that at 60% penetration of distributed generators the system operates optimally at which 40% of electricity to be produced from centralized power plants connected at inner ring. Table 6 shows the losses in the proposed power system configuration with the distributed generators connected at outer ring. The losses get reduced with increasing DGs penetration.

Environmental impact: There is now strong scientific evidences of happening the climate change, which is being accelerated by human activities. The world is getting warmer. 21st century has been witnessing

Table 5: Simulation results of 24-bus system (interconnected distribution network) with distributed generators penetration

	Load		Generation/ no penetration of DGs			Generation/10% penetration of DGs			Generation/ 20% penetration of DGs		
Bus no.	P_L	Q_L	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage
1	30.5	10.8	171.6	96.45	1.085	158.6	90.37	1.070	142.30	79.35	1.063
2	45.3	24.7	40.0	25.81	1.070	35.0	21.26	1.061	31.55	20.70	1.059
3	55.8	30.2	30.0	21.14	1.072	28.0	19.83	1.060	26.25	17.25	1.058
4	47.6	25.4	0.0	0.00	1.063	0.0	0.00	1.057	0.00	0.00	1.051
5	58.7	26.3	0.0	0.00	1.058	0.0	0.00	1.051	0.00	0.00	1.047
6	0.0	0.0	0.0	0.00	0.955	0.0	0.00	0.965	0.00	0.00	0.968
7	0.0	0.0	0.0	0.00	0.835	2.0	1.10	0.843	0.00	0.00	0.860
8	0.0	0.0	0.0	0.00	0.785	2.0	1.00	0.827	5.00	2.30	0.852
9	12.0	8.0	0.0	0.00	0.882	0.0	0.00	0.893	0.00	0.00	0.910
10	10.0	6.0	0.0	0.00	0.885	0.0	0.00	0.894	0.00	0.00	0.915
11	9.0	5.0	0.0	0.00	0.925	0.0	0.00	0.930	0.00	0.00	0.938
12	14.0	8.0	0.0	0.00	0.930	0.0	0.00	0.935	0.00	0.00	0.942
13	15.0	9.0	0.0	0.00	0.905	0.0	0.00	0.910	0.00	0.00	0.927
14	10.0	8.0	0.0	0.00	0.885	0.0	0.00	0.903	5.00	2.30	0.928
15	6.0	3.0	0.0	0.00	0.810	2.0	1.00	0.841	4.00	2.10	0.889
16	10.0	6.0	0.0	0.00	0.827	0.0	0.00	0.846	0.00	0.00	0.878
17	5.0	3.0	0.0	0.00	0.795	2.0	1.00	0.837	5.00	2.20	0.880
18	15.0	11.0	0.0	0.00	0.905	0.0	0.00	0.908	2.00	1.00	0.918
19	8.0	5.0	0.0	0.00	0.904	2.0	1.10	0.912	0.00	0.00	0.917
20	15.0	10.0	0.0	0.00	0.910	0.0	0.00	0.915	0.00	0.00	0.923
21	13.0	8.0	0.0	0.00	0.853	0.0	0.00	0.882	2.00	1.10	0.896
22	5.0	3.0	0.0	0.00	0.821	2.0	1.10	0.855	2.00	1.10	0.865
23	10.0	6.0	0.0	0.00	0.814	2.0	1.20	0.845	5.00	2.60	0.880
24	3.0	2.0	0.0	0.00	0.835	2.0	1.10	0.882	2.00	1.00	0.894

	Generation/30% penetration of DGs			Generation/40% penetration of DGs			Generation/50% penetration of DGs			Generation/60% penetration of DGs		
Bus no.	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage	P_G	Q_G	Voltage
1	109.55	62.82	1.052	84.25	43.85	1.040	69.2	57.00	1.035	48.5	32.15	1.022
2	30.70	17.50	1.045	24.35	14.70	1.031	20.0	13.55	1.027	20.0	11.35	1.013
3	23.15	15.30	1.041	20.05	12.25	1.033	15.0	9.85	1.021	15.0	12.15	1.012
4	0.00	0.00	1.042	0.00	0.00	1.032	0.0	0.00	1.024	0.0	0.00	1.017
5	0.00	0.00	1.038	0.00	0.00	1.035	0.0	0.00	1.031	0.0	0.00	1.020
6	0.00	0.00	0.973	0.00	0.00	0.980	0.0	0.00	0.985	5.0	2.60	0.995
7	0.00	0.00	0.960	0.00	0.00	0.973	0.0	0.00	0.988	5.0	2.10	1.003
8	5.00	2.30	0.905	5.00	2.30	0.960	6.0	2.90	0.976	10.0	4.50	1.001
9	0.00	0.00	0.925	5.00	2.90	0.950	10.0	4.70	0.983	6.0	2.30	0.990
10	2.00	1.10	0.941	5.00	3.10	0.965	4.0	1.30	0.980	10.0	5.60	0.998
11	5.00	2.10	0.970	0.00	0.00	0.982	2.0	1.10	0.997	4.0	2.10	1.007
12	4.00	2.10	0.953	3.00	1.60	0.978	3.0	1.20	0.994	4.0	1.90	1.010
13	0.00	0.00	0.935	4.00	1.80	0.955	6.0	2.80	0.986	5.0	2.20	1.005
14	5.00	2.40	0.942	3.00	1.10	0.968	4.0	1.70	0.996	0.0	0.00	1.020
15	0.00	0.00	0.927	4.00	1.90	0.955	6.0	2.70	0.998	5.0	2.40	1.012
16	5.00	2.30	0.910	5.00	2.10	0.965	4.0	1.60	0.990	5.0	2.30	1.007
17	5.00	2.20	0.952	3.00	1.00	0.973	3.0	1.10	0.993	4.0	1.80	1.001
18	0.00	0.00	0.930	4.00	1.30	0.965	4.0	1.70	0.988	3.0	1.20	0.995
19	3.00	1.30	0.945	5.00	2.60	0.963	4.0	1.80	0.986	2.0	1.10	0.994
20	2.00	1.10	0.930	4.00	2.30	0.958	5.0	2.20	0.983	8.0	4.30	0.998
21	2.00	1.10	0.915	4.00	2.10	0.950	10.0	4.10	0.980	10.0	5.30	0.977
22	5.00	2.60	0.905	5.00	2.20	0.952	5.0	2.10	0.994	0.0	0.00	1.010
23	3.00	1.30	0.984	0.00	0.00	1.010	0.0	0.00	0.990	5.0	2.30	1.008
24	2.00	1.00	0.940	5.00	1.80	0.963	4.0	1.80	0.992	5.0	2.40	1.003

serious threat to the progress of human civilization due to deficiency of energy. As on date more than 90% of global energy requirements are fulfilled by burning of fossil fuels with the consequent release of green house gas emissions that impose serious warning to the environmental security for the future generations. The electricity consumption rate has grown much faster than the replenishment of its reserves and as a result the global energy crisis has been raised to an alarming level.

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 (Chel *et al*., 2009). This intensity factor is modified for Indian conditions by multiplying with factor 1.45 which accounts for 25% loss of energy in transmission and distribution and 20% of loss due to the use of inefficient electric equipments at power plants. Hence, the revised intensity factor for CO_2 emissions is 1.421 kg of CO_2 per kWh of electrical energy generation from coal based thermal power plants. The carbon emission has been quantified in the Table 7.

Table 6: Network losses of proposed configuration with distributed generator penetration

Line		Losses in MW						
From	To	No DGs	10% DGs	20% DGs	30% DGs	40% DGs	50% DGs	60% DGs
1	3	0.43470	0.43250	0.41250	0.38734	0.35341	0.32078	0.29431
1	6	0.44327	0.4412	0.41720	0.40743	0.37284	0.33465	0.29743
2	3	0.54723	0.54348	0.52832	0.51273	0.48539	0.41738	0.34863
2	4	0.44379	0.44264	0.42875	0.39718	0.35693	0.31096	0.28248
2	6	0.43238	0.43113	0.41775	0.38857	0.33874	0.30561	0.26841
2	7	0.31243	0.31169	0.30130	0.28638	0.22957	0.20593	0.17892
3	4	0.15535	0.15421	0.15007	0.13506	0.11321	0.09873	0.08874
4	8	0.16579	0.16511	0.15802	0.14172	0.12035	0.09987	0.08237
5	7	0.17746	0.17712	0.17408	0.15843	0.12087	0.10069	0.08934
5	8	0.16317	0.16201	0.16071	0.14681	0.12328	0.09754	0.08863
9	10	3.92137	3.82028	3.51508	1.78431	1.03569	0.92921	0.69269
10	11	3.37219	3.35721	2.84793	2.01893	1.20758	0.87806	0.67358
11	12	2.95213	2.90324	2.78403	2.14276	1.31735	0.93063	0.79561
12	13	2.71037	2.70022	2.67482	2.08538	1.13024	0.90362	0.75292
13	14	2.54309	2.52404	2.50431	1.87063	1.17642	0.92629	0.77228
14	15	2.73025	2.52952	2.47693	1.96832	1.23208	0.89953	0.73418
15	16	3.45323	3.38108	3.27259	2.18365	1.27808	0.91407	0.78835
16	17	2.75017	2.55230	2.43024	1.70748	1.12874	0.85731	0.76749
17	18	3.54219	3.45137	3.12054	2.06581	1.21762	0.86684	0.79652
18	19	3.73426	3.60328	3.60291	2.18093	1.17409	0.87068	0.76742
19	20	2.85027	2.58235	2.32504	1.82857	1.10823	0.90847	0.81583
20	21	3.87310	3.28032	3.07836	2.33483	1.45791	0.92037	0.75538
21	22	3.41357	3.25407	3.13804	2.18741	1.18065	0.91225	0.73294
22	23	3.05787	2.86346	2.79368	2.08132	1.13086	0.91276	0.67638
23	24	3.40129	3.10825	2.93732	2.12631	1.48837	0.91562	0.78482
24	9	3.29543	3.10287	3.10209	2.32065	1.21094	0.91321	0.76431
2	9	3.72318	3.12032	2.81562	2.13824	1.30354	0.97503	0.65437
7	12	2.81046	2.63055	2.50753	1.90438	1.22473	0.95307	0.68648
5	14	3.21045	3.05124	2.74035	1.88682	1.18723	0.87538	0.58893
8	17	3.21350	3.02122	2.88320	1.86587	1.60548	0.98861	0.65583
4	18	3.72857	3.65129	2.95302	2.07503	1.39651	0.96126	0.72869
3	20	2.35213	2.89223	2.65725	1.80951	1.28709	0.97591	0.78659
1	22	3.89317	3.33272	2.83418	2.01275	1.12316	0.88682	0.65934
6	24	3.79219	3.62548	2.95624	1.85846	1.43282	0.83286	0.64981

Table 7: Simulation results of various network configurations

Network configurations		Electricity generation from fossil fuel based centralized power plants (MW)	T and D network losses (MW)	CO$_2$ emission in kilotons
Simulation results of 5-bus system		153.051	3.05248	150.0000
Simulation results of 10-bus system and distribution network (radial)	Without DGs	213.800	53.80000	209.5240
	With 10% DGs	192.240	48.24000	188.3952
	With 20% DGs	171.300	43.30000	167.8740
	With 30% DGs	150.700	38.70030	147.6860
	With 40% DGs	129.600	33.60000	127.0080
	With 50% DGs	107.400	27.40000	105.2520
	With 60% DGs	86.900	22.90000	85.1620
Simulation result of 24-bus system and distribution interconnected network	Without DGs	241.600	81.60000	236.7680
	With 10% DGs	221.600	77.60000	217.1680
	With 20% DGs	200.100	72.10000	196.0980
	With 30% DGs	163.400	51.40000	160.1320
	With 40% DGs	128.650	32.65000	126.0770
	With 50% DGs	104.200	24.20000	102.1160
	With 60% DGs	83.500	19.50000	81.8300

CONCLUSION

The analysis of proposed power system configuration shows that increase in penetration of large-scale renewable electricity generating units has a large impact on the future need for electricity infrastructure reconfiguration.

This study primarily concern three main issues:

- Increased load demand cannot be met by present power system infrastructure.
- The drive to meet out the electricity requirement by harvesting the energy from various available sustainable energy sources.
- There is need to minimize electricity generation from fossil fuel based power plants and also mitigates GHG emissions.

The proposed power system configuration has two rings topologies; inner ring topology already exists which large capacity generators are connected supplying power to the consumers through radial feeders and outer ring allows the small capacity distributed generators. The inner ring to be responsible for balancing the grid operation reliably during intermittent electricity generation from renewables. The proposed interconnected distribution network configuration minimize the electricity generation from fossil fuel based centralized power plants and also make the nation energy sufficient.

The proposed power system configuration will boost the green house gas emission mitigating efforts and also empower the consumers as they can produce electricity by installing solar panels and small wind generators on their premises for their use and if excess electricity is generated, it may be stored or sell back to the utility at competitive cost.

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