Swarm Intelligence Approach for Optimum Renewable Integration of Campus Microgrid – A Case Study

Saritha K. S.*, Sasidharan Sreedharan, S. R. Anand, and Usha Nair

Abstract— *This paper proposes a novel control strategy for optimum renewable integration of a campus microgrid connected to the utility grid. In the proposed system model, renewable energy (wind) penetration is optimized for economical operation. The proposed micro-grid model consists of renewable energy sources such as solar PV, wind, biomass and energy storage units and the utility grid includes the most inexpensive conventional power generators (hydel) and static compensators. The performance of the integrated network is analysed in terms of its voltage stability, active power flow, eigenvalue stability for the stable and reliable operation. In this paper, the electrical network simulation is performed using PSAT MATLAB toolbox which is globally accepted power system simulation software and the power flow computation is carried out using the Newton-Raphson's method. Integration of microgrid with the utility grid helps to improve the stability, import/export electric power from/to the main grid. Also, power quality, flexibility and reliability increase the overall social performance of the campus micro grid system.*

Keywords— **Power grid, microgrid, batteries, reliability.**

1. INTRODUCTION

In the modern power world, reformation of the electrical power sector is emerging especially in the generation sector due to technological development, environmental concern, and demand of a reliable and economically viable power supply. Presently, Solar photovoltaic and wind power are the booming source of electricity which is economically compatible, environmentally sustainable and technologically established. With the wide penetration of renewable resources into the existing electrical power system, many changes have been taken place due to intermittency and seasonal changes of the solar and wind power. This issue can be solved by incorporating an efficient storage system for the power system. For the future power system, microgrid/smart grid is the most inevitable and promising part and has been considered as the best solution for the electrical power shortage problems.

Liberalization and deregulation in the electricity market and open access to power grid has made a new face to Indian power system, especially in the generation sector. More DGs based on RESs have incorporated in the conventional power system thereby the distribution sectors turned to an active network. Fortunately, all the Government energy policies also promoting the renewable energy integrated power system. Now the Kerala State Electricity Board also in line with the new concept. Hence this proposal may be a pilot project in the Kerala power sector.

This paper examines the effect of microgrid-main grid (utility grid) integration and aim to optimize the renewable energy (wind) incorporated in the microgrid and hence make the system more economical, efficient and flexible. This problem involves selecting the generating units satisfying the demand-supply power balancing without violating the system constraints and maximize the renewable energy share thereby minimize the fuel cost.

2. LITERATURE REVIEW

Integration of non-conventional type energy sources enhance the reliability of the power system and make it more flexible than a single source. Moreover, renewable resources will result in a reduction of conventional power generation (fossil fuel) environmental pollution and definitely the production cost. Many types of research are going on in the field of alternative energy sources like Electric vehicles and wind power and the results show that these are the most promising alternative source in the future and their inclusion with the conventional power generating sources reduces the operational and emission cost in electric power industry [1]. Consequently, the renewable penetration to the conventional power system is increased nowadays and globally this becomes a great concern [2]. In paper [3] the major technical challenges and its possible solution related to the wind integration into the power system were explained in detail. The main issues of wind integration are effects of wind power on the power network, power system operating cost and power quality. The study revealed that wind power's impacts on system operating cost are small at low wind penetrations and moderate at higher penetration level and the author tries to give some possible solution to ensure and maintain the reliability of the wind power into the grid.

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Optimal placement and size of DGs play an important role on voltage stability margin, grid losses and DG reactive power limits [4]. A performance study of the renewable energy sources integration into the smart grid is explained in paper [5]. This paper provides the role of renewable energy in the smart grid system. In this, the author commented that considering the techno-economical aspects a PV smart grid system model to be developed to evaluate the electricity price for integrating PV in a smart grid. Among the RESs, solar PV system is a clean energy source and recognizing its advantages, PV installation is much more in recent years.

A Hierarchical framework is proposed for optimal generation scheduling of RESs and BESS in a day ahead market and proved that this approach makes the system more reliable and economical [6]. Stand-alone and grid connected mode of Distributed generators (DGs) helps in generation enhancement and integration of distributed energy resources (DERs) with main grid helps improvement in power quality, reliability, and flexibility.

Lack of proper utilization of the available RESs and judicial power management are the main reasons behind the existing energy crisis. In future smart grid/ microgrid will replace the conventional system and thereby reduce the consumer cost and fossil fuel dependency [7]. Even though renewable energy sources have minimum operating cost than conventional type, their stochastic nature especially, solar and wind make the system unstable. Hence adequate power reserve (storage) or additional supports must be included in the system for reliability [8].

A micro-grid which effectively integrates renewable energy resources (RESs) with diesel generators and energy storages can be a good alternative for new generation strategy and energy management [9]. The scheme consists of generators in the form of RESs or fossil fuel, load, and energy storage devices such as batteries, EVs etc. [10]. Paper [11] explain the recent ongoing trends in grid integration of RESs like solar and wind energy system and the power quality issues associated with the integration. In this, the author describes technical and non-technical issues related to the integration and proposes some possible solutions to overcome the intermittency of renewable energy power generation. The effect of MG on the voltage stability is described in paper [12] and in this study, the author describes the positive effects of an integrated MG into power system.

From the above literature review, it is clear that a dynamic change in the conventional power system is mandatory to cope with the electrical energy requirement and social, environmental and techno-economical aspects of the modern world. Microgrids can locally distribute electrical loads in a more economical and eco-friendly way. The survey also reveals the challenges, possible solutions and the benefits of renewable energy integration to the power system.

Distributed energy resources connected to the grid provide an alternative or to enhance the performance of the conventional power system. By proper scheduling of the DGs connected in the system, generation cost as well as power loss can be reduced in a mutally beneficial manner to both microgrid as well as the the central power grid. The study in paper [13] analyses the operational performance of integrated microgrid with the power grid in terms of peak load shaving and minimization of peak load demand of the grid. Unfortunately, the stated paper has not considered the stability of the system which is one of the essential criteria far as the grid integration. A review on grid integration technical issues for microgrid management is illustrated in paper [14]. This paper concludes that reactive power management and voltage control is the prime requirement for stable and reliable operation in microgrid integration. In paper [15], energy management in microgrid is described and the study includes various demand response programs and its impact on optimal energy management. For the optimization modelling, many constraints such as power balance, Consumer load, charging - discharging constraints were considered but the vital parameter, reactive power management and voltage stability issues were not taken into account. So current work is formulated as addressing the drawback of the above said issue.

Presently there is drastic change happening in the global energy sector. Every Government is now promoting new entrepreneurs to the world of renewable energy-based power generation. Consequently, Power system becomes localized and the integration of such localized grid into the main grid will affect the normal operation and system performances. Whenever the main grid weakens, any interruption occurs or load enhancement in the main system, the integrated microgrid can support and reduce the congestion in the main grid to some extent. So, the impact of such integration must be analysed in many aspects and various researches are going on in this area. Lots of research papers are available for microgrid integration, but in many cases, the stability analysis has not been considered seriously. Considering the above research gaps, this paper proposes the integration of the hybrid microgrid into utility grid and tries to analyse the impact of the grid integration.

The main contributions of this work are enlisted as follows:

- A campus microgrid has been integrated into power (Utility) grid and optimized the RESs (wind) penetration.
- Impact of microgrid - main (utility) grid integration has been analysed.
- Voltage stability and small signal stability has been considered while optimizing the renewable energy source in the microgrid.
- Analysis has been carried out for microgrid & main grid in its independent mode as well as in the integrated mode.
- An economical and eco-friendly energy management has been proposed in this paper
- This proposal may be useful for the upcoming energy revolution in the electric power sector.

3. PROPOSED METHODOLOGY AND MODELLING

The methodology of this proposal includes modelling a campus electrical network into a microgrid - laboratory model and integrates this proposed microgrid to the utility grid. After collecting grid data, optimize the wind penetration considering the system constraints. The power flow analysis is executed using the Newton-Raphson method and the objective function is to minimize the active power loss without violating the system constraints. The proposed methodology is as shown in Figure 1.

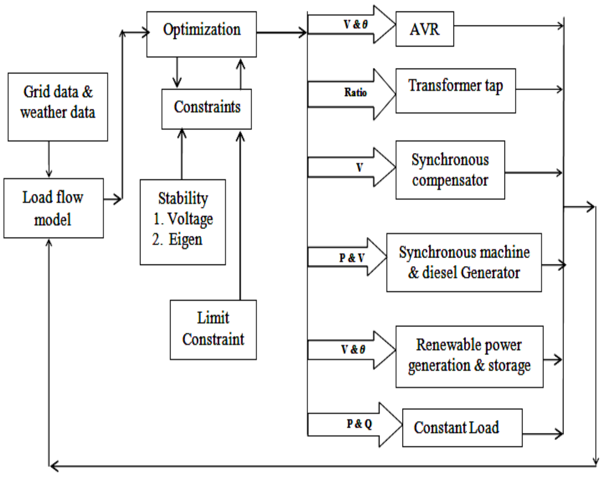

Fig. 1. Proposed Methodology.

3.1 *Modeling of Power System Components*

The proposed microgrid-main grid integrated system is modeled as a 30-bus system. The main (utility) grid includes conventional type generators (hydel) 4 nos, and synchronous compensator of 80MVAR capacity and loads. The microgrid (MG) consists of RESs such as Solar PV, Wind power unit, Biomass, Diesel generators and battery energy storage system (Solid Oxide Fuel Cell) and loads. In this model, all the loads are considered as constant PQ type.

Solar Photo voltaic generator (SPVG): In the proposed network, constant PV solar photovoltaic generator is considered. A compact model of a constant PV solar photovoltaic generator is shown in Figure 2[16]. This dynamic model is suitable for distributed generator applications.

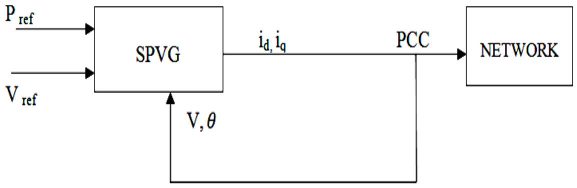

Fig. 2. SPVG constant PV model.

All the other components in the proposed system are as described in Table. 1.

Table 1. Power system model description

Component	Model Details
Wind model	Composite type, wind speed 15m/sec.
Wind turbine	Variable speed wind turbine with Doubly Fed Induction Generator (DFIG).
Storage system	Solid oxide fuel cell (SOFC) Number of cells: 384 Ideal standard potential: 1.18 V
Solar PV generator	Constant PV solar photo voltaic generator
Generator	Synchronous, Order V, Type II
Automatic Voltage Regulator (AVR)	IEEE Type II
Load	Constant PQ

4. PROBLEM FORMULATION

In this paper, a micro-grid consisting of renewable sources such as solar, biomass, wind energy source and among this wind power generation is optimized as it is more economical and almost no greenhouse gas emissions compared to others. This project aims to integrate the proposed micro-grid (which is set up from a campus power network) to the utility grid and analyse the impact of microgrid-main grid integration.

4.1 Objective Function:

Minimization of active power loss is the objective function considering the equality and inequality system constraints. The objective function is formulated as:

$$Minimize\ F(x,u) = \sum_{i=1}^{Nl} P_{loss\ i} \quad ; Nl = \text{No.of lines in the system} \quad (1)$$

where, $P_{loss,i}$ = P_{mn}+P_{nm} = active powerloss at i^{th} line between node *m* and node *n*.

P_{mn} is the power flow from m^{th} node to n^{th} node

$$P_{mn} = \left(e_m f_n - e_n f_m\right) B_{mn} + \left(e_m^2 + f_m^2 - e_m e_n - f_m f_n\right) G_{mn}$$

$$P_{loss,i} = G_{nm}\left(\left(e_n - e_m\right)^2 + \left(f_n - f_m\right)^2\right) \quad (2)$$

where e_m, f_m are the real and imaginary part of complex node voltage of m^{th} node; G_{mn}, B_{mn} are the real and imaginary part of the admittance of the line between m^{th} and n^{th} node.

Subjected to the equality constraints; *g(x,u) = 0.*

$$\left.\begin{aligned} P_{Gi} - P_{Di} &= \sum_{j=1}^{N}\left(e_i\left(e_j g_{ij} - f_j b_{ij}\right) + f_i\left(f_j g_{ij} + e_j b_{ij}\right)\right) \\ Q_{Gi} - Q_{Di} &= \sum_{j=1}^{N}\left(f_i\left(e_j g_{ij} - f_j b_{ij}\right) - e_i\left(f_j g_{ij} + e_j b_{ij}\right)\right) \end{aligned}\right\} \quad (3)$$

where, P_{Gi} and Q_{Gi} is the total active and reactive generation at i^{th} bus; P_{Di} and Q_{Di} is the total active and reactive load at i^{th} bus; N is the number of nodes/buses in the system.

The inequality constraints $h(x, u) \leq 0$ are:

Thermal constraints

$$\left.\begin{aligned} &P_{line} \leq P_{line}^{max} \text{ ; active powerflow through the line} \\ &Q_{line} \leq Q_{line}^{max} \text{ ; reactive powerflow through the line} \\ &S_{line} \leq S_{line}^{max} \text{ ; apparent powerflow through the line} \end{aligned}\right\} \quad (4)$$

Active power, reactive power & bus voltage limits

$$\left.\begin{aligned} &\left.\begin{aligned} &\left|P_{Gi}^{min}\right| \leq \left|P_{Gi}\right| \leq \left|P_{Gi}^{max}\right| \\ &\left|Q_{Gi}^{min}\right| \leq \left|Q_{Gi}\right| \leq \left|Q_{Gi}^{max}\right| \end{aligned}\right\} \text{ ; generator power limit} \\ &\left|V_i^{min}\right| \leq \left|V_i\right| \leq \left|V_i^{max}\right| \quad \text{ ; bus voltage limit} \\ &\left|d_i^{min}\right| \leq \left|d_i\right| \leq \left|d_i^{max}\right| \quad \text{ ; bus voltage phase angle limit} \\ &\left.\begin{aligned} &P_{wind} \leq P_{wind\ max} \\ &Q_{wind} \leq Q_{wind\ max} \end{aligned}\right\} \text{ ; wind power generation limit} \\ &P_{SPV} \leq P_{SPV\ max} \text{ ; solar PV real power generation limit} \\ &P_B \leq P_{B\ max} \quad \text{ ; BESS real power limit} \end{aligned}\right\} \quad (5)$$

In Equation (1), x and u are the state and control variables. In this analysis, slack bus power P_G, load bus voltage V_i, generator reactive power outputs Q_G, apparent power S_i are taken as the state variables.

State variable x can be expressed as:

$$x^T = \left[P_{Gi}, V_{K+1} \ldots V_N, Q_{Gi} \ldots Q_{GK}, S_1 \ldots S_N\right] \quad (6)$$

where K = total number of generator bus.

The generator real power outputs P_G except at the slack bus P_{G1} and generator voltages V_G, are considered as control variable u and can be expressed as;

Control variable; $u^T = [P_{G2} \ldots\ldots P_{Gk}, V_{G2} \ldots V_{Gk}]$. (7)

4.2 Swarm Intelligence Approach:

Particle Swarm Optimization (PSO) is an optimization technique based on simulation of a simplified social system, designed and developed by J. Kennedy and R. Eberhart [17]. It is a simple & robust metaheuristic method based on a combination of social science and computer science. This method can generate high quality solution within an acceptable computation period. In this technique, each particle changes its position according to their own experience and move around in a multi-dimensional search space with some initial velocity. During this process, each particle updates their position and velocity to find their best position in the search space, as per equation (8) & (9) respectively [18,19].

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (8)$$

$$v_i^{k+1} = w^k * v_i^k + c_1\left[rand_1\left(p_{best,i} - x_i^k\right)\right] + c_2\left[rand_2\left(g_{best} - x_i^k\right)\right] \quad (9)$$

where, i - the particle index
k - discrete time index
v - velocity of i^{th} particle
w^k - inertia weight function
x - position of the i^{th} particle
c_1 & c_2 - weighting factor
$rand_1$&$rand_2$ - random numbers on the interval(0,1)
p_{best} - best position found by the i^{th} particle
g_{bset} - best position found by the group
(best of personal bests).

For faster convergence and better result, inertia weight approach can be used and the function is as per equation (10) shown below.

$$w^k = w_i - \frac{w_i - w_f}{k_{\max}} * k \quad (10)$$

where, w_i - initial weight
w_f - final weight
k_{max} - maximum iteration number
k - current iteration number.

In this work, PSO method can be adopted for optimizing the RE penetration with minimum power loss, without violating the system constraints. Thus, power generation scheduling can be done in a most economical way.

The Algorithm for the optimal RE penetration for the proposed system is described as follows:

Step 1. Input system data (line data, bus data, source data, voltage limits, line limits, system constraints, and PSO settings.).

Step 2. Generate initial population of particles with random positions and velocities in the solution space. Set the iteration counter k = 0.

Step 3. For each particle, obtain the objective value and compare with the individual best. If the objective value is higher than P_{best}, set this value as the current P_{best} and record the corresponding particle position.

Step 4. Select the particle associated with the minimum individual best P_{best} of all particles, and set the value of P_{best} as the current overall G_{best}.

Step 5. Update the velocity and position of the particle.

Step 6. If the iteration number reaches the maximum limit, go to Step 7. Otherwise, set iteration index k = k + 1 and go back to Step 3.

Step 7. Display the output.The best particle denoted by G_{best} gives the best solution to the target problem.

Figure 3 gives the flowchart of the swarm intelligence approach for the above stated algorithm.

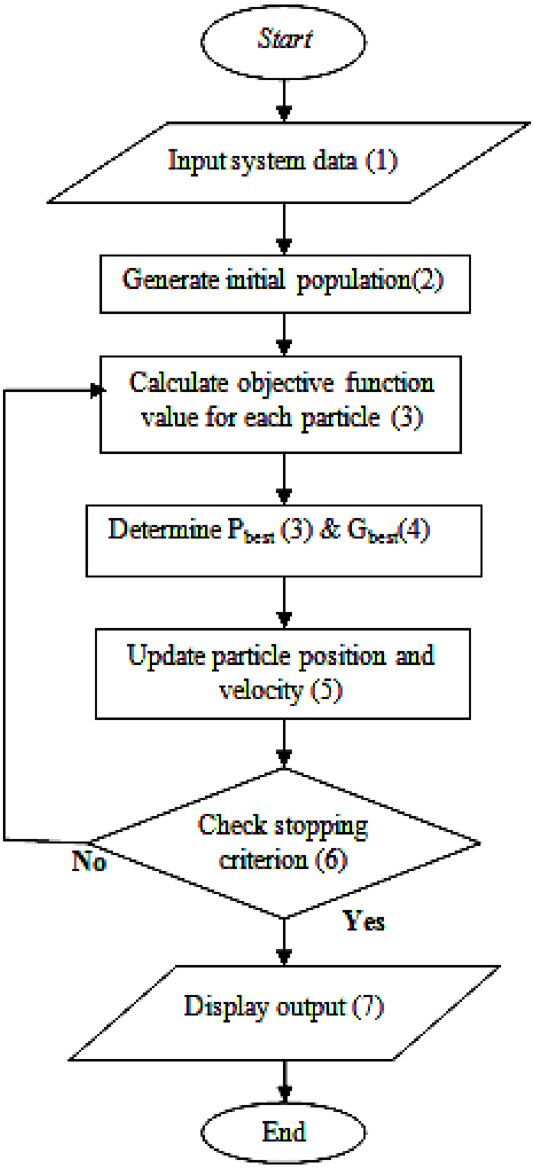

Fig.3. Flowchart for the swarm intelligence approach

5. RESULTS AND DISCUSSION

A campus network is set up as the proposed microgrid and the utility grid is taken as the central region of Kerala power grid. This region consists of 4 hydel generating stations mainly Idukki, Sabarigiri, Kakkad, and Edappon. The network is covered mainly in 4 districts Kottayam, Pathanamthitta, Idukki, and Alappuzha. The power flow of the grid is carried out using Newton –Raphsons method and the software used is a globally accepted power system simulation tool – PSAT [20]. The proposed network is analysed in terms of voltage stability, small signal stability and eigenvalue analysis for the stable and reliable operation of the micro-grid as well as the **main grid.**

Figure 4 shows the PSAT model of the campus microgrid and a symbolic diagram of the integrated micro-grid with utility grid is shown in Figure 5. The Newton Raphson method is used for the power flow computation and static analysis is conducted.

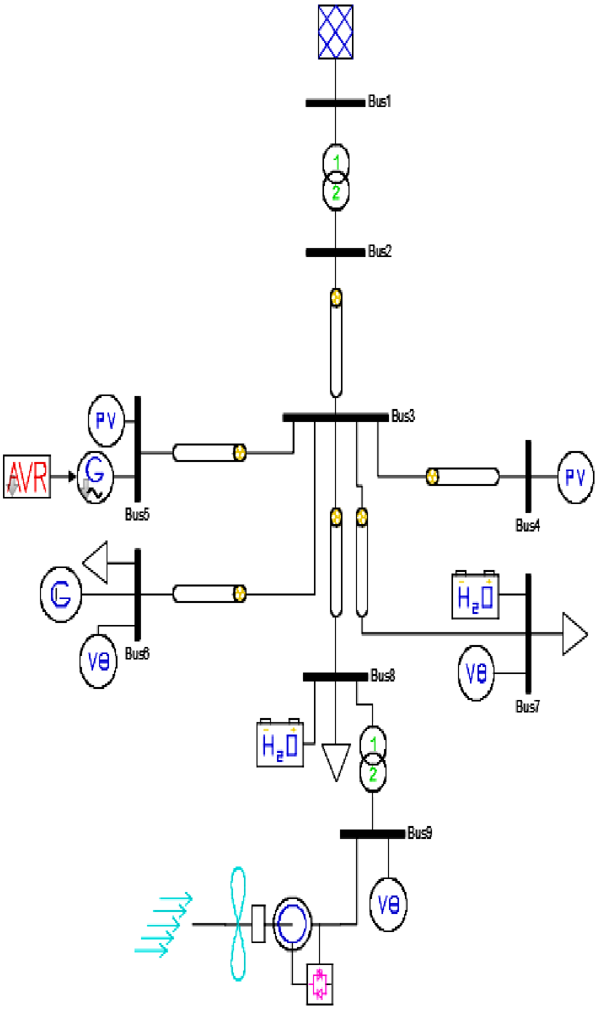

Fig.4. Microgrid model of Campus Network.

After individual analysis, the micro-grid is coupled to the utility grid and power flow is carried out and the result is as shown in Table 2. The proposed microgrid is self-sustainable as well as can contribute power to the main grid in the grid connected mode.

From Table 2, it can be observed that the active power loss developed in microgrid is 10. 65% and when it is connected to utility grid the active power loss occurred for the entire system is only 3.44%. Before integration the power loss for the main grid (utility) was 3.42%, so only a slight increment in active powerloss occurred due to integration with the microgrid. Hence, by integration method the overall system loss can be reduced much. In micro-grid, as the DGs are near to the load centre the transmission and distribution (T&D) losses can be minimized.

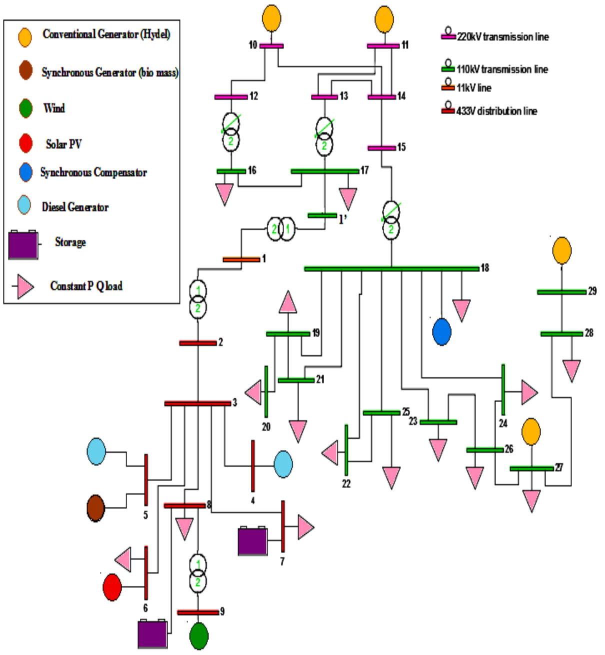

Fig. 5. Symbolic model of the integrated microgrid with Utility grid

Table 2. Power flow report

Source	Micro-grid	Utility-grid	Integrated grid
Total generation			
Real power (MW)	1.315	983.67	985.08
Reactive power (MVAR)	0.872	488.61	485.89
Total load			
Real power (MW)	1.176	950.00	951.18
Reactive power (MVAR)	0.860	447.95	448.90
Total losses			
Real power (MW)	0.140	33.665	33.902
Reactive power (MVAR)	0.012	40.655	36.988

In Table 3, distribution of power from micro grid and utility grid sources are shown. When the micro-grid is integrated with the main grid, the share from renewable sources is increased and consequently, there is a reduction of power from conventional sources connected in the main grid. The system become more economical and ensure eco - friendly environment due to the integration. Bidirectional power flow can be achieved through the integration and hence both the microgrid as well as main grid become more reliable/secure than their independent mode.

Table 3. Active power generation

Source	Active Power generation (MW)	
	Before integration	After integration
Microgrid	1.234	1.968
Utility grid	983.673	983.107

The simulation results in Table 2 and 3 clearly show that by the integration of renewable energy sources into a system, the T&D losses and the power generation from conventional sources reduces. The dynamic behaviour of the MG depends on the geographic nature of the system as well as the characteristics of the DGs and the control mode of their interface with the utility grid. Thus, the integration of micro-grid with the main grid (Utility grid) results in a reduction of generation cost, without violating the system constraints and also keeping the power balance.

Figures 6 and 7 shows the power generation profile of microgrid and utility grid during individual operation and on integrated mode. From Figure 6, it can be seen that wind power is optimized in both the cases.

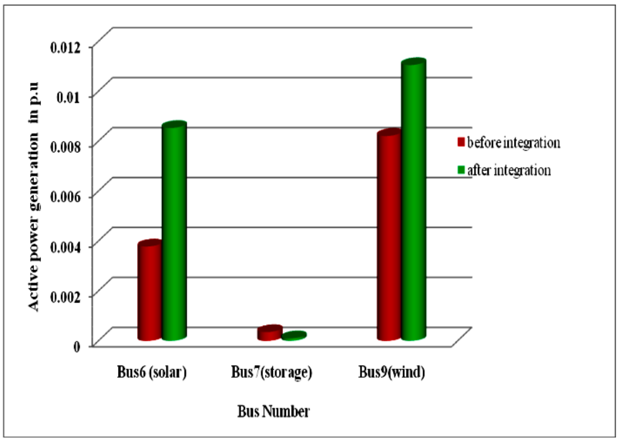

Fig. 6. Active power generation from microgrid.

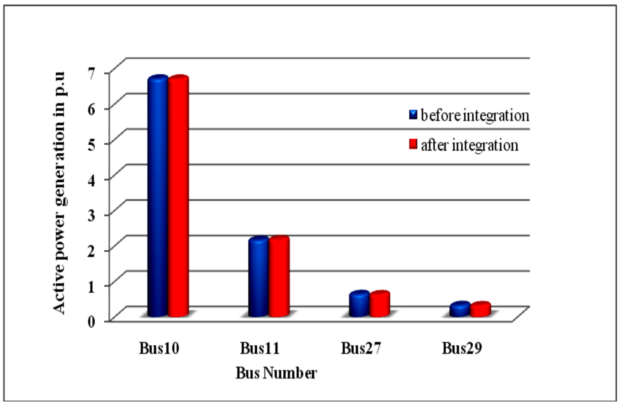

Fig.7. Active power generation from Utility grid

Figures 8 and 9 shows the voltage profile of micro-grid and utility grid and it can be seen that all the bus voltages are within the permissible limit (0.9 pu -1.1

p.u). Moreover, there is an improvement in bus voltage after the integration of micro-grid with the utility grid. As the microgrid is of low capacity, there is no significant increase in main grid bus voltages (only slight improvement in bus voltage after integration). All the main grid bus voltages keep the voltage level as before.

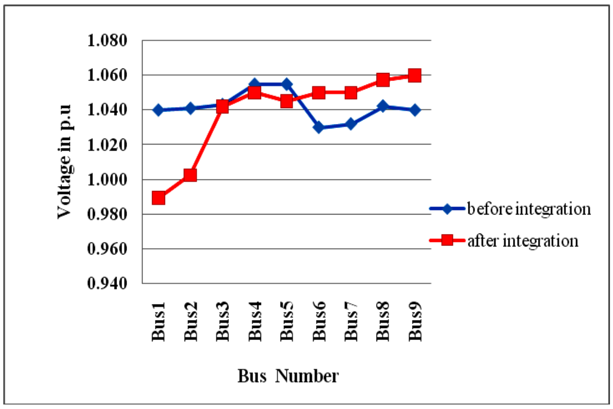

Fig. 8. Microgrid Voltage profile.

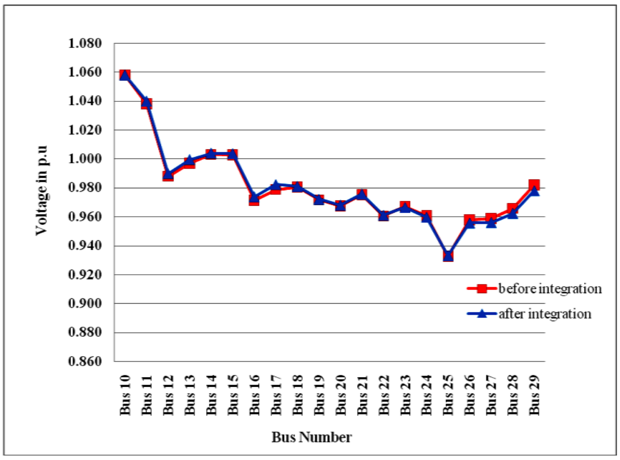

Fig. 9. Utility grid voltage profile.

The system stability can be analysed by the eigenvalue analysis and the Figures 10 to 12 shows the S domain analysis of the micro grid, utility grid and its grid connected mode.

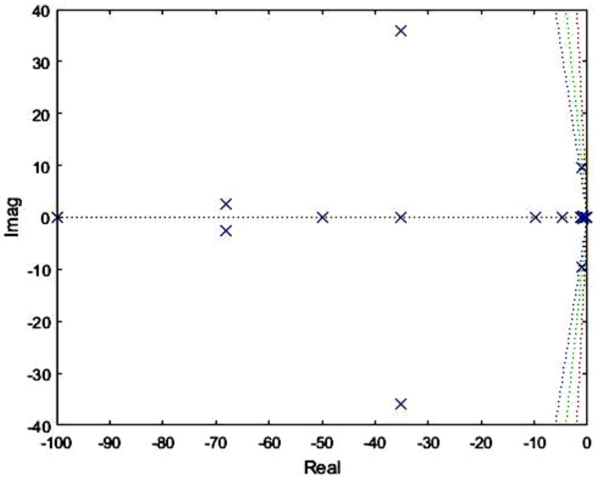

Fig.10. Microgrid - S domain.

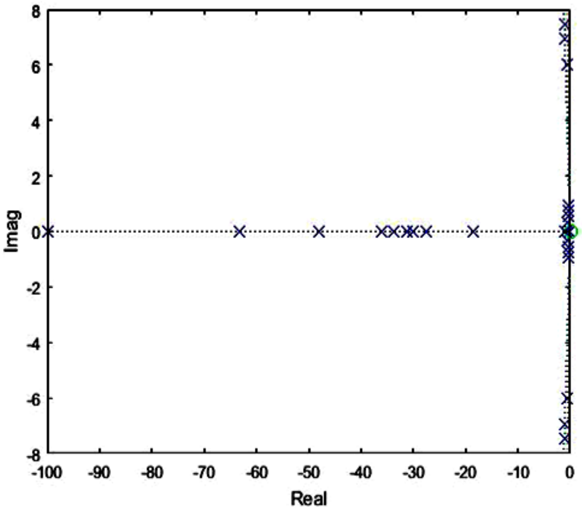

Fig. 11. Utility grid - S domain.

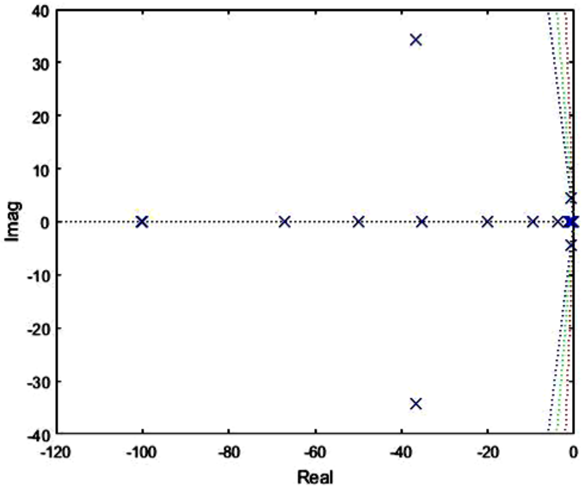

Fig. 12. Integrated Micro grid-Utility grid - S domain.

In S domain, it can be seen that all the roots are in the left half of S plane which shows the stable condition of each network.

Figures 13 &14 shows the active power flow of the microgrid and utility grid lines, before and after integration.

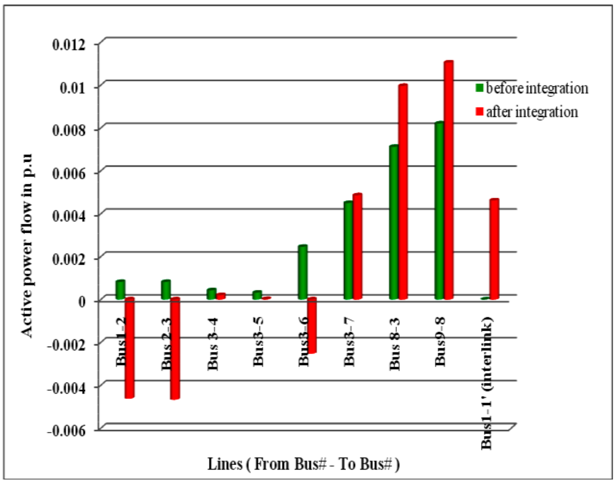

Fig. 13. Active power flow in microgrid.

From Figure 13, it can be seen that, in most of the lines the active powerflow improved after integration and also it is reversed in some of the lines. One advantage of grid integration is bi- directional powerflow. In this case, power flow is from microgrid to main grid through the interconnection i.e. Bus1-1’.

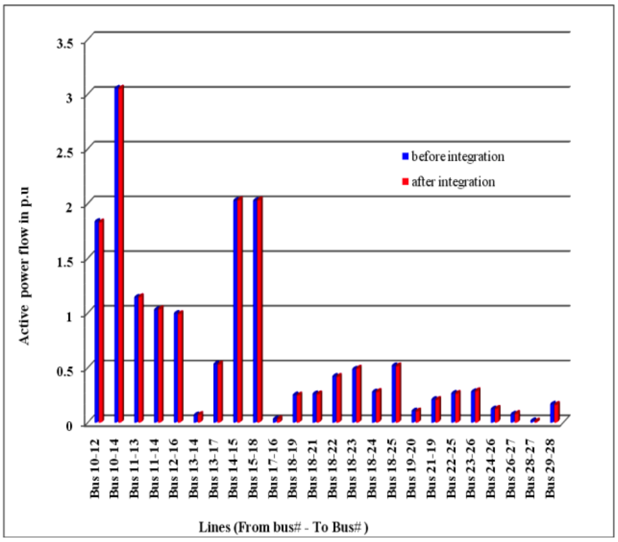

Fig.14. Active power flow in Utility grid(Power grid).

From the Figure 14, it can be observed that in utility grid there is not much variation in the powerflow due to integration. The reason is that, as the power grid system is very large compared to the microgrid, the impacts of grid integration will be less in powergrid. But large scale integration of microgrid into powergrid may badly affect the system performances of the powergrid. From the Figure 13 & 14, it can also be identified that the most oveloaded lines are Bus 8-3 & Bus 9-8 in microgrid and in maingrid, Bus10-14, Bus14-15 and Bus15-18 respectively.

6. CONCLUSIONS

This paper presents a study on grid integration and their performance correlated with the integration of micro-grid into a utility grid. In the proposed system model, renewable energy (wind) penetration is optimized for economical operation. The proposed micro-grid is integrated with the practical grid (utility) and the static analysis is performed. The simulation results show that after integration, bus voltages of microgrid and utility grid are improved. Moreover, during the integration, the active power exchange between the microgrid and main grid is mainly contributed by wind power and consequently, there is a reduction in power from the conventional generators. It can be concluded that by the integration of micro-grid with main grid, there is voltage improvement in the system with a reduction in power loss as well as maximum penetration from renewable sources are achieved. With the integration of a greater number of micro-grids into the main grid, the effect will be more significant.

Since the solar and wind resources are stochastic in nature, high penetration of such sources with frequent and uncontrollable variability and difficulty in controllability with respect to the grid requirements will result in stretching other conventional generators and the grid as a whole and may even lead to reduction in the resilience and reliability of the grid. On the balancing of real power, the impact is shared by the conventional generators and load or both. The reactive power balancing issues may require more investment in the transmission and distribution side for corrective actions, which are dynamic in nature. So, in real time operation, necessary tools must be available with system operator to control the impact of unexpected variation from RESs. In particular, the spinning reserve shall be capable of accommodating the ramping during such variations in RE generation.

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