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# Modelling and Optimization of Grid Interconnected Co-Generation for Fulfilment of Power Demand at Economic Cost through Transmission Network

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***Abstract— Due to growing population, industrialization, technological advancement and improvisation in living standard promotes more need of energy. Energy plays vital role in activities associated with micro and macro scale development as well as economic growth. In India 65% of population belongs from rural area or engaged in agricultural and allied services. Primary (Agriculture) sector is backbone of Indian Economy so for productive development in agricultural area required utilization of advance mechanization but for this ensurity of electricity is prior concern. Through government initiatives in electrification schemes such as RGGVY, PMGY, KJY, AREP etc. have strengthened transmission network for getting electricity throughout the nation. Still most of the rural areas are experiencing lack in electricity due to minimum demand or improper load scheduling, unavailability of require generation and more transmission losses. In this paper modeling of Grid interconnected Cogenerations system has formulated in such a way that it will fulfil power demand, precise load schedulement and delivery of power at economic cost.***
***Keywords— Energy Model, Cogeneration, Optimal Power Flow, Economic Load Dispatch, Demand Side Management.***

## I. INTRODUCTION

India's electricity demand increases by 4.8% of total generation since 2010. But still India faces large energy deficit in total and peak power demand of 2.1% and 3.2 % respectively. [1] In India almost 80 % of power generation done by conventional sources gives adverse environmental impact. In India, 65% of population is living in rural region and engaged in agriculture and local activities. For productive improvement in agriculture sector needs utilization of advance technology and surety of electricity for it. Big initiatives by government through social schemes such as RGGVY, PMGY, KJP, AREP etc. which improve percentage of electrification although 3.32 % of villages are unelectrified due to high cost in grid expansion for low electricity demand. Day-by-day rise in energy requirement increases dependability of fossil fuels which arises issues like global warming, loss in biodiversity, pollution and threat of diminishing energy sources. Transmission system plays major role in terms of power system stability and reliability in power delivery. Only increment in generation capacities is not perfect solution to fulfil energy demand. It requires proper sizing of generation sources, maximum efficiency, low losses and stability of power system, reliability in transmission, precise load side-demand side management and most important environment sustainability. To overcome all circumstances of electricity demand and surety of 24 × 7 uninterrupted supply needs proper planning and management from load side to generation systems. For that purpose require simple, user-friendly tool of energy planning which helps to get optimum usage of available energy by lowering system losses with economic dispatch of generated power to equalize required demand of load centre

## II. MODELING OF GRID INTERCONNECTED CO-GENERATION SYSTEM

Modeling is formulated system purposely created for acquisition of particular output from set of input provided to it. Energy modeling is way to demonstrate present situation of energy scenario, future demand and related macroeconomic activities in context of energy usage, peak demand and environmental impact. Modeling of grid interconnected energy system intentionally created to analyse present demand of power, performance of energy system as well as transmission network and achieve better efficiency with cost economy in existed condition.[5] It is essential part of simulation engineer for Schedulement of total and peak power demand with maintaining efficiency by reducing loss of transmission system.

 

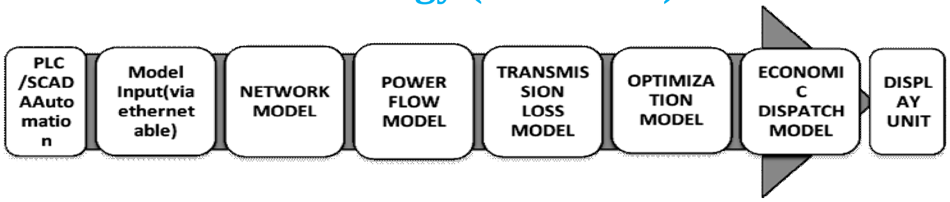


Fig. 1 Process Flow Diagram of Proposed Model

Interconnected Grid Transmission System allow easy entrance for private or individual power producer (IPP) so it make competitive environment about power generation and also shares power demand which will helpful for equalizing load factor. To make sure about uninterrupted power supply need proper scheduling of available generation for efficient and economical performance of generation. Co-generation plants are basically Combined Heat power (CHP) plants builded for purpose of own source of energy whenever doesn't need of energy or sometimes more available at outlay can effectively sold to SEB grid for earning profit. It is having overall 75-80% efficiency due to unuseful low pressure steam further utilized for heating purpose.

### A. Network Model

Network model is used to calculate admittance matrix ($Y_{bus}$) from individual feeder resistance and reactance. It has done with node-voltage method applying KCL at each bus. The network equations are complex non-linear algebraic equations in terms of node current. Network model uses line data from input model for computation of $Y_{bus}$ which further utilized in power flow analysis. For n-bus network model demonstrated as follows:

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_i \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & \cdots & Y_{1i} & \cdots & Y_{1n} \\ Y_{21} & Y_{22} & \cdots & Y_{2i} & \cdots & Y_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ Y_{i1} & Y_{i2} & \cdots & Y_{ii} & \cdots & Y_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ Y_{n1} & Y_{n2} & \cdots & Y_{ni} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_i \\ \vdots \\ V_n \end{bmatrix}$$

$$\mathbf{I}_{bus} = \mathbf{Y}_{bus}\,\mathbf{V}_{bus}$$

Where

$V_{bus}$ = Vector of bus voltages

$I_{bus}$ = Vector of the injected currents (the current is positive when flowing into the bus and negative when flowing out of the bus)

$Y_{bus}$ = Admittance matrix.

### B. Power Flow Model

Power flow model is used to determine current, voltage, active power and reactive volt-ampere at various points in a power system operating under normal-steady or static condition. Load flow studies are made to plan the best operation and control of existing system as well as to plan the future expansion to keep pace with load growth. [5] Such studies help in asserting the effects of new load new generation stations, new lines and new interconnections before they installed. The prior information serves to minimize system losses and to provide a check on system stability. In proposed model Newton-Raphson method is preferred to find out transmission factor due to fast convergence and less time taken in simulation.

$$\begin{aligned} I_i &= y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n) \\ &= (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \cdots - y_{in}V_n \end{aligned}$$

or

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij}V_j \qquad j \neq i$$

### C. Transmission Loss Model

To evaluate exact transmission losses of complex network uses Kron technique but it requires all the entities associated with transmission network which can be obtained from power flow model. It expresses system losses in terms of interconnected generator's real power output. It also called B-coefficient method.

$$P_L = \sum_{i=1}^{n_g}\sum_{j=1}^{n_g} P_i B_{ij} P_j + \sum_{i=1}^{n_g} B_{0i} P_i + B_{00}$$

*D. Optimization Model*

Optimization model of grid interconnected energy system is better way to fulfil power demand of proposed study area because it's having ability to expand output at certain limit and also it operated at full capacity gives performance improvisation and better efficiency. The objective function of optimization model is fulfil demand using local generation system with their real power limit which reduces transmission losses due to overcapacity and long distance transmission of power. Quadratic Programming is an effective optimisation method if the objective function is quadratic and the constraints are linear. It can be applied to optimisation problems having non-quadratic objective and non-linear constraints by approximating the objective to quadratic function and the constraints as linear. For all the four problems the objective is quadratic but the constraints are also quadratic so the constraints are to be made linear. Transformation of variables technique7 is incorporated for making the constraints linear. This is explained as follows.

Put $P_i + (U_i\text{-}L_i), X_i$ where $0<X_i<1$ in the objective function and constraints.
Make the constraints linear by neglecting the second order terms for the constraints
Apply QP to solve the optimisation problem find the solution vector [P].

*E. Economic Dispatch Model*

The economic load dispatch (ELD) of power generating units has always occupied an important position in the electric power industry. ELD is a computational process where the total required generation is distributed among the generation units in operation, by minimizing the selected cost criterion, subject to load and operational constraints. For any specified load condition, ELD determines the power output of each plant (and each generating unit within the plant) which will minimize the overall cost of fuel needed to serve the system load [3]. ELD is used in real-time energy management power system control by most programs to allocate the total generation among the available units. ELD focuses upon coordinating the production cost at all power plants operating on the system.

From Kron loss formula,

$$P_L = \sum_{i=1}^{n_g}\sum_{j=1}^{n_g} P_i B_{ij} P_j + \sum_{i=1}^{n_g} B_{0i} P_i + B_{00}$$

The objective function is to minimize overall generating cost Ci which is function of plant output,

$$C_t = \sum_{i=1}^{n_g} C_i$$

$$= \sum_{i=1}^{n} \alpha_i + \beta_i P_i + \gamma_i P_i^2$$

Subject to the constraint that generation should equal to demand plus losses i.e.

$$\sum_{i=1}^{n_g} P_i = P_D + P_L$$

But generator provided minimum and maximum output power limit expressed as follows

$$P_{i(min)} \le P_i \le P_{i(max)} \qquad i = 1, \ldots, n_g$$

Using Lagrange's constrained function, get following equation,

$$\mathcal{L} = C_t + \lambda(P_D + P_L - \sum_{i=1}^{n_g} P_i)$$

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From iterative process by gradient method get ;

$$\sum_{i=1}^{n_g} \frac{\lambda^{(k)}(1-B_{0i}) - \beta_i - 2\lambda^{(k)} \sum_{j\neq i} B_{ij} P_j^{(k)}}{2(\gamma_i + \lambda^{(k)} B_{ii})} = P_D + P_L^{(k)}$$

or

$$f(\lambda)^{(k)} = P_D + P_L^{(k)}$$

Expanding the left hand side of above equation in Taylor's series about an operating point $\lambda^{(k)}$ and neglecting higher order terms result in

where

$$\sum_{i=1}^{n_g} \left(\frac{\partial P_i}{\partial \lambda}\right)^{(k)} = \sum_{i=1}^{n_g} \frac{\gamma_i(1-B_{0i}) + B_{ii}\beta_i - 2\gamma_i \sum_{j\neq i} B_{ij} P_j^{(k)}}{2(\gamma_i + \lambda^{(k)} B_{ii})^2}$$

and therefore,

$$\lambda^{(k+1)} = \lambda^{(k)} + \Delta\lambda^{(k)}$$

where

$$\Delta P^{(k)} = P_D + P_L^{(k)} - \sum_{i=1}^{n_g} P_i^{(k)}$$

The process in continued until $\Delta P^{(k)}$ is less than specified accuracy.

Network model, Power Flow model, Loss model, Economic Dispatch model are sub model of grid interconnected energy system. It should be organized in sequential manner to get precise results as notified from objective function i.e. optimum and cost economy of generation. All sub-models are formulated in MATLAB software which is having user-friendly approach with ease of modification facility. The flow chart of Optimal Economic Load Dispatch algorithm is as shown in below.

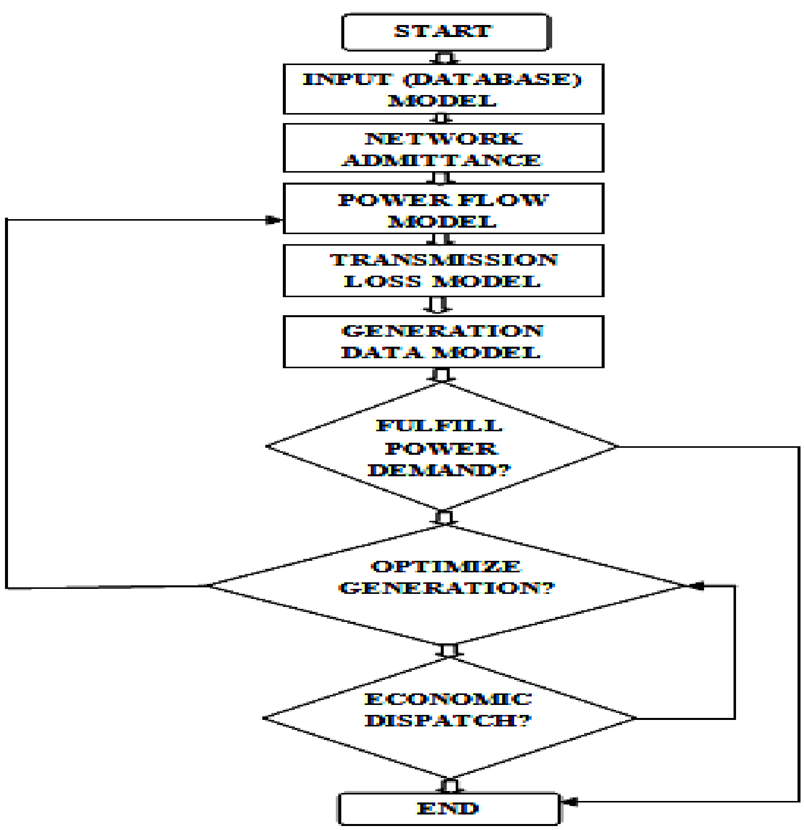


Fig. 2 Flow Chart of Optimal and Economic Dispatch Model

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## III. SIMULATION RESULTS AND DISCUSSION

To verify the feasibility and effectiveness of the proposed model, grid interconnected power systems were tested on is two co-generation units. Results of proposed Optimal and Economic Dispatch Model are simulated in MATLAB package. A reasonable B-loss coefficients matrix of power system network has been employed to calculate the transmission loss. In this case, a standard two-unit co-gen power plant (IEEE 5 bus test system) is used to demonstrate.

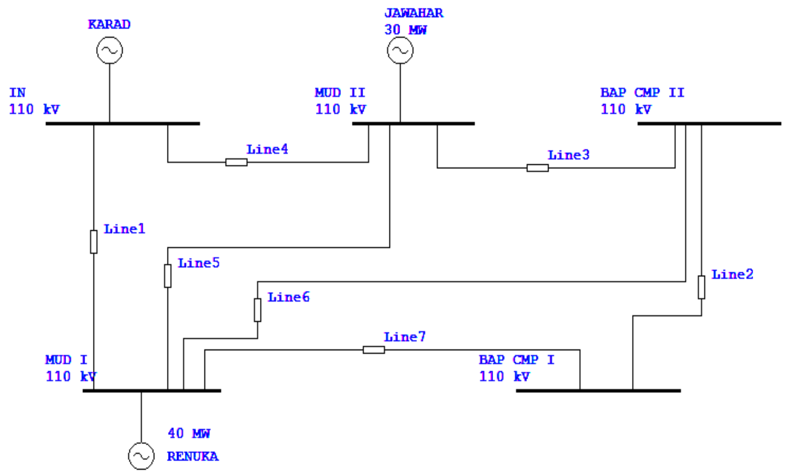


Fig. 3 Single Line Diagram of IEEE-5 bus Interconnected Grid Transmission Network

### A. Network Model Output

$$\begin{bmatrix} 6.25-18.69j & -5+j15 & -1.25+j3.75 & 0+j0 & 0+j0 \\ -5+j5 & 10.8-j32.4 & -1.67+j5 & -1.67+j5 & -2.5+j7.5 \\ -1.25+j3.75 & -1.67+j5 & 12.91-j38.7 & -10+j30 & 0+j0 \\ 0+j0 & -1.67+j5 & -10+j30 & 12.91-j38.7 & -1.25+j3.75 \\ 0+j0 & Y52 & 0+j0 & -1.25+j3.75 & 3.75-j11.2 \end{bmatrix}$$

### B. Power Flow Model Output

TABLE I
SIMULATION RESULT OF POWER FLOW MODEL

| Bus No | \|Voltage\| | Angle (°) | Load | | Generation | |
|---|---|---|---|---|---|---|
| | | | MW | MVAR | MW | MVAR |
| 1 | 1.06 | 0.0 | 0 | 0 | 0 | 0 |
| 2 | 1.045 | -0.74 | 20 | 10 | 40 | 30 |
| 3 | 1.03 | -1.142 | 20 | 15 | 30 | 10 |
| 4 | 1.056 | -1.82 | 50 | 30 | 0 | 0 |
| 5 | 0.96 | -3.23 | 60 | 40 | 0 | 0 |

### C. Transmission Loss Model Output

$$=[P1 \quad P2 \quad P3]\begin{bmatrix} 0.0265 & 0.0141 & 0.0083 \\ 0.0141 & 0.0276 & 0.0103 \\ 0.0083 & 0.0103 & 0.0019 \end{bmatrix}\begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} + [P1 \quad P2 \quad P3]\begin{bmatrix} 0.0003 \\ 0.0025 \\ 0..0019 \end{bmatrix} + 0.0005$$

$$= 0.0265\, P_1^2 + 0.0141\, P_1 P_2 + 0.0083\, P_1 P_3 + 0.0141 P_1 P_2 + 0.0276\, P_2^2 + 0.0103\, P_2 P_3 + 0.0083 P_1 P_3 + 0.0103 P_2 P_3 + 0.0019 P_3^2$$

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$+0.0003P_1+0.0025P_2+0.0019P_3+0.0005$

### *D. Generator Cost Function And Constraints*

TABLE III
SIMULATION INPUT OF GENERATION LOADING MODEL

| Generator | Cost function ($\alpha_i+\beta_iP_i+\gamma_iP_i^2$) | Generator Real Power Limit | |
|---|---|---|---|
| | | Min. Generation | Max. Generation |
| GENCO | $190+5.2P_1+0.0065P_1^2$ | 10 | 150 |
| COGEN-1 | $160+4.3P_2+0.0072P_2^2$ | 10 | 40 |
| COGEN-2 | $125+4.8P_3+0.0058P_3^2$ | 10 | 30 |

### *E. OELD Model Output*

1) Total Demand of 110 kV Grid = 150 MW.
2) Optimize Generation Output: = 154.4227 MW.
   GENCO = 84.43MW; COGEN-1 = 40MW; COGEN-2 = 30MW.
3) Total Transmission Loss = 4.4227 MW

### *F. Cost Of Generation in $/h of 110 kV Grid Connected Cogeneration Plant*

TABLE IIII
SIMULATION RESULTS OF ECONOMIC DISPATCH MODEL

| Power Inlet | Without Optimization | With Optimization |
|---|---|---|
| GENCO | 710.65 | 675.75 |
| COGEN-1 | 343.52 | 343.52 |
| COGEN-2 | 274.22 | 274.22 |
| TOTAL | 1328.39 | 1293.49 |

Simulation result shows that both the objectives has accomplished by precise schedulement of generation considering transmission losses and delivery of power in economic cost which saves 34.9 $/h in present situation.

From present study and analysis of grid interconnected co-generation model obtained following observations such as

Grid interconnected energy system model able to ensure delivery of maximum power as per actual demand and available generation.

Optimized operation of existed generation push towards fulfillment of energy need and boost overall efficiency of generation system due to generator operated at full rated capacity.

Optimal Dispatch Model ensures equalization of deficit margin between actual demand and available generation, economic cost of operation and consideration of transmission losses while scheduling of load.

Proposed model is developed by focusing especially Karveer taluka due to multi-dimensional approach in context of rural and urban region as well as various sectoral demand considerations i.e. agricultural, domestic, industrial, commercial etc. for planning scheduling and management of power at demand side.

## IV. CONCLUSIONS

The efficient, optimum and economic operation of grid interconnected power system is important motive of power sector companies. The efficient use of the available generation is growing in importance, because to demand increment issue can't be solved only installing or upgrading new capacity plants. A savings in the operation of generating systems of a small percent represents a significant reduction in operating cost which gives profit to generation companies as well as grows the performance of generation system. The optimum operation of the system involves the economy of operation, system security, reliable and ensures power supply and most important fulfillment in load demand. Therefore prime objective of power generation at minimum cost and low transmission losses offers effective workout in power transmission as well as economic scheduling and effective management of power for demand centers.

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## V. ACKNOWLEDGMENT

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