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Om Hari Gupta
Vijay Kumar Sood
Om P. Malik *Editors*

Recent Advances in Power Systems

Select Proceedings of EPREC-2021

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Editors

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Electrifying Hilly Remote Habitation by Solar Photovoltaic System

Chandramohan, Siva Ramakrishna Madeti, and Krishna Murari

1 Introduction

Owing to the increasing population, industrialization, and urbanization the energy demand all over the world is on the rise. Most of the energy consumption is in the form of electricity and it is considered an important resource from the economic and development point of view. Although India is being one of the developing countries, still millions of people are suffering from energy poverty. The main reason for energy poverty in rural areas in India is due to the ignorant decisions taken by policymakers. After the 1980s, access to energy in the household was introduced in National Five-Year Development Plan. As per 2019 census data, even after 74 years of independence, 240 million people in India have no access to electricity and 819 million people are living without a clean cooking facility [IEA, 2019]. According to official data, in 2017 only 1,417 of India's 18,452 villages, or 7.3% of the total, have 100% household connectivity, and about 31 million homes are still in the dark. Electrifying remote location by extending the national power grid is not possible. Therefore, it is necessary to provide access to electricity through some other means.

Installation of diesel generators is a potential alternative for rural electrification. They can provide electricity at a lower cost. In spite, however, of this advantage, there were serious drawbacks, such as the fuel cost becomes expensive and safety problems are associated with transportation. Moreover, generators produce high carbon-intensive electricity.

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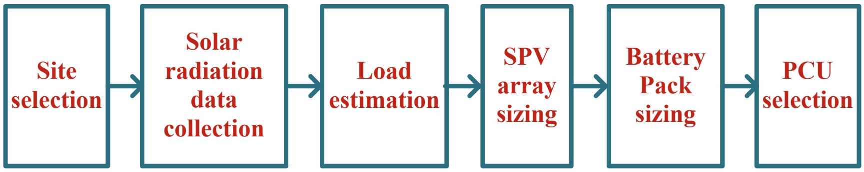

Fig. 1 Flowchart for designing off-grid solar photovoltaic (SPV) system

Unlike fossil fuels, renewable energy sources are virtually inexhaustible and available in all regions of the world [1–3]. In this regard, a standalone generation of electricity from renewables becomes an attractive and climate-friendly option for rural electrification. Among all renewable energy sources, solar energy is the most reliable and viable source [4, 5]. In addition, rapid developments in the field of photovoltaic (PV) technologies have taken place over the last few decades, and the government is also providing various financial subsidies to the electricity generation sector using PV technology [6, 7]. These trends are expected to continue in the future, making PV technologies more attractive for rural electrification. Figure 1 shows the evolution of the price of crystalline PV modules in different markets. The PV technology's conversion efficiency rate was 12–15% in the 1990s; today, it can reach a value of up to 25%.

The national electricity policy mandates state electricity authorities to provide one unit of energy per day per household at remote locations by standalone mode. During the last couple of years, most of the Indian states are facing problems in supplying electricity even to the domestic and commercial consumers already connected with grid networks due to more dependency on fossil fuel and hydro-based power plants. As one of the solutions, the Government of India announced Jawaharlal Nehru National Solar Mission (JNNSM) and encourages solar energy systems in all the states by providing financial assistance.

Many researchers have contributed papers on designing the solar photovoltaic system and on assessing the economic viability of the system. Some of these are solar power generation during different months [8], the optimum size of a standalone photovoltaic system [9], solar photovoltaic sizing procedure [10], evaluation procedure for different photovoltaic schemes [11], evaluation of the photovoltaic design by probabilistic methods [12], socio-economic and environmental impacts [13], features of rural electrification in India [14], and cost-break-even analysis [15]. By using earlier literature works, solutions to health issues, migration to a nearby town, more work hours to increase productivity and more monthly income, less dependency on seasonally rain-fed crop and lighting of remote locations have been given through off-grid solar photovoltaic systems. Several off-grid, as well as hybrid, solar photovoltaic power plants are functioning in many remote places in the state of Rajasthan, Bihar, Maharashtra, Uttar Pradesh, West Bengal, Karnataka, Tamilnadu and other states of India.

To our present state of knowledge, no article that treated the different designing aspects completely and systematically has been published. In this paper, a methodology including the relevant designing points, starting with the prediction of load demand up to the assembly of the best optimal system configuration, is introduced. In this paper, a solution for electrifying a remote hilly habitation using a solar photovoltaic system has been given and a reliable power design with 2 days battery backup has been proposed for the same. Further, the economic viability of the proposed system has also been carried out.

2 Methodology

The following methodology has been used to design an off-grid solar photovoltaic system:

1. Site has been identified,
2. Field survey has been carried out by personal visit for
   a. Load estimation (number of households, number of common loads),
   b. Site selection for solar photovoltaic power plant,
   c. Shadow analysis,
   d. Planning of power distribution network and streetlight pole points.
3. Solar radiation data has been used from NASA and Ministry of New and Renewable Energy (MNRE), Government of India database,
4. Other necessary data and observations (accessibility to site, modes of transportation) have been collected/made by a site visit.

Figure 1 shows the step-by-step procedure for designing an off-grid solar photovoltaic (SPV) system.

3 Introduction

This section provides the sizing methodology for various components of the solar photovoltaic (SPV) system.

3.1 Solar Photovoltaic Array Sizing

To supply the expected load at the site, the required capacity of solar photovoltaic has been selected by using the following expression [16]:

$$\text{Total Watt peak} = \frac{\text{Load in Wh}}{(\text{Peak Sun Hour} \times \text{ SPV system efficiency})} \tag{1}$$

The efficiency of the SPV system has been considered as 68% accounting for all the system losses such as photovoltaic soiling, photovoltaic mismatch, photovoltaic thermal, battery efficiency, direct current and alternating current cable losses and inverter efficiency. Peak sun hour has been considered during winter months at the site. 120 V is the suitable system voltage for remote village electrification having a lower installed capacity. A lesser weight module should be selected for easy transport at a hilly remote location. The total number of modules required can be estimated by using the following expression:

$$\text{Number of PV modules} = \frac{\text{Total peak Watt}}{\text{Individual module Peak Watt}} \tag{2}$$

Number of modules (Ns) in a string is estimated by using the following expression:

$$\text{Ns} = \frac{\text{PV System voltage}}{\text{Unit module voltage}} \tag{3}$$

Number of strings (Np) in an array is estimated by using the following expression:

$$\text{Np} = \frac{\text{Total number of modules}}{\text{Ns}} \tag{4}$$

3.2 Battery Pack Capacity

For a typical remote hilly location with a cost-effective design, 2 days of battery backup is sufficient since there will not be any critical loads. A higher number of autonomies would require a greater number of batteries which would increase the total cost of the solar photovoltaic system as 40% of the total cost is spent on the battery pack. Battery bank (BB) capacity in ampere-hour (Ah) has been estimated by considering battery bank depth of discharge (BBDOD) as 80%, battery bank efficiency ($BB\eta$) as 90%, temperature de-rating factor for site temperature condition, battery pack voltage of 120 V and alternating current efficiency (AC $\boldsymbol{\eta}$) of 93%.

$$\text{BBAh} = \frac{\text{SupplyWh}}{(\text{BBDODx BB}\eta\text{x AC}\eta\text{x BBVoltagex Tempderatingfactor})} \tag{5}$$

where supply Wh is the energy to be stored by a battery pack and is calculated as:

$$\text{SupplyWh} = \text{Load watt hour x (Battery Autonomy } + 1) \tag{6}$$

Here, load watt-hour is the energy required by all the connected loads. 2 V cell, 1850 Ah, unit capacity of maintenance-free, and valve-regulated lead-acid (VRLA) tubular gel batteries [17] are suitable for off-grid solar photovoltaic application since these do not require any electrolyte top-up and maintenance.

3.3 Power Conditioning Unit (PCU)

The input voltage of PCU must be matched with photovoltaic array output voltage, i.e. 120 V DC and output voltage must be matched with load voltage, i.e. 240 V AC. Inverter output power ratings have been selected to supply 1.2 times the normal connected load to handle any extreme and future growth situation [18]. The rating of an inverter is estimated by the following expression:

$$\text{Nominal current} = \frac{\text{Total connected load}}{\text{Nominal load voltage}} \tag{7}$$

Here, the nominal current is the operating current of an inverter and the nominal load voltage is the operating voltage of connected loads. Overload current is the maximum current that an inverter can handle.

$$\text{Overload current} = 3 \text{ x Nominal current} \tag{8}$$

4 Economic Viability

Life cycle (LC) costing is used in the design of a photovoltaic system that will cost the least amount over its lifetime [19]. Life cycle costing in general constitutes a sensible means for evaluating any purchase options. It is a sum of all the costs of an SPV system over its lifetime expressed in today's money. The cost which is incurred before the plant starts its commercial operation is known as capital cost. The life cycle or lifetime period (Term or years) of the solar photovoltaic system has been considered as 20 years. General price escalation (GE) has been considered as 5% per annum and discount rate (DR) has been considered as 9%.

4.1 Life Cycle Capital Cost

The present worth of life cycle (LC) capital cost has been estimated by the following expression:

$$\text{Present worth of LC capital cost} = \text{capital cost} \times \left\{ \frac{1 + \text{GE}}{1 + \text{DR}} \right\} \tag{9}$$

4.2 Life Cycle Operation and Maintenance Cost (LCOMC)

The expected annual operation and maintenance cost (AMC) of a solar photovoltaic system has to be estimated by practical experiences by comparing similar kinds of plants in operation. The life cycle operation and maintenance cost is estimated as follows:

$$\text{LCCOMC} = \text{AMC}\left[\left\{ \frac{1 + \text{GE}}{\text{DR} - \text{GE}} \right\} \times \left\{ 1 - \left\{ \frac{1 + \text{GE}}{1 + \text{DR}} \right\}^{\text{TERM}} \right\} \right] \tag{10}$$

Here, TERM refers to the lifetime period of the SPV power plant.

4.3 Life Cycle Replacement Cost

From the manufacturers' data, it has been found that the lifetime of valve-regulated lead-acid tubular gel battery is 6.5 years. So every seventh-year battery pack has to be replaced with a new battery pack. The cost occurred to replace the battery pack is estimated by using the following expression.

$$\text{LC Replacement Cost} = \sum \text{Battery pack cost} \times \left[\left(\frac{1 + \text{GE}}{1 + \text{DR}} \right)^{\text{TERM}} \right] \tag{11}$$

Here, TERM refers to the year of battery pack replacement.

4.4 Total Life Cycle Cost

The life cycle (say 20 years) cost of an off-grid solar photovoltaic system can be estimated as follows:

$$\begin{aligned} \text{Total Life cycle cost} &= \text{Present worth of LC capital cost} \\ &\quad + \text{LC operation and maintenance cost} + \text{Life cycle Replacement Cost} \end{aligned} \tag{12}$$

4.5 Annual Energy Generation (AEG)

Annual energy generation from a solar photovoltaic system has been estimated by the following expression:

$$\text{AEG} = \text{Installed Capacity x Annual average daily PSH x 365} \quad (13)$$

4.6 Unit Electricity Cost (UEC)

The cost of unit electricity of an off-grid solar photovoltaic system has been worked out by using the following expression:

$$\text{Life cycle Unit Electricity Cost} = \frac{\text{Life cycle Cost}}{\text{Lifetime of PV plant x Annual energy}} \quad (14)$$

The unit electricity cost estimated by (14) is without subsidy from the Government of India. The off-grid solar photovoltaic system is eligible for central financial assistance (CFA) of 81 rupees per watt of installed capacity in India [20]. Therefore, by calculating CFA, the solar photovoltaic system can avail subsidy from the Ministry of New and Renewable Energy sources. The unit electricity cost of the solar photovoltaic system will reduce further after considering the subsidy amount.

5 Case Study

5.1 Site Location

Malliamman durgam is a remote habitation in Guthiyalathur village, Sathyamangalam taluk in Erode district of Tamil Nadu state (India), and is located on the Western Ghats of Kadambur forest region, 13 km from Kadambur foothills. It is located geographically 11°35′ North and 77°20′ East at the altitude of 1235 m. Geographical coordinates and altitudes have been estimated by using a GPS navigator at the site. Topographically, it is a hilly area having a semi-arid dry sub-humid climate and receives a maximum temperature of 38 °C and a minimum of 16 °C and it receives annually 730 mm rainfall [14]. As of February 2013 census taken from school teachers of Malliamman durgam, 259 people (128 male, 131 female) are living in a total of 73 households. Among the population, there are 34 school-going children. The entire population is an agro-based community and depends mostly on locally cultivated broad beans, guava fruit, jack fruit and gooseberry (Phyllanthus

Fig. 2 Location map of Malliamman durgam

emlica) and ragi. The average monthly income of a family with two members is INR 2500–3000. Figure 2 shows the location of the identified site in India.

5.2 Solar Radiation Data

The data for monthly average daily global solar radiation on the horizontal surface have been collected from NASA and MNRE, Government of India database. Solar radiation data available for the geographical location 11° 41′ N and 77° 17′ E have been used to size the solar photovoltaic system. From the collected data, it is found out that the annual average solar radiation at the site is 5.2 kWh/m^2/day and the peak sun hour (PSH) during winter months (November to January) is 4.7 h[10]. Figure 3 shows the month-wise average solar radiation at different tilt angles ranging from 0° to 45°. To harness the maximum solar energy throughout the year, the solar panel has to be fixed at an angle near the site latitude [19].

5.3 Load Estimation

The load required to be supplied has been estimated by collecting data by personal visits to the site. The power demand for domestic needs has been estimated with the help of a questionnaire format prepared especially for the habitation, and habitants were asked to fill the questionnaires. The load data contains the details about the

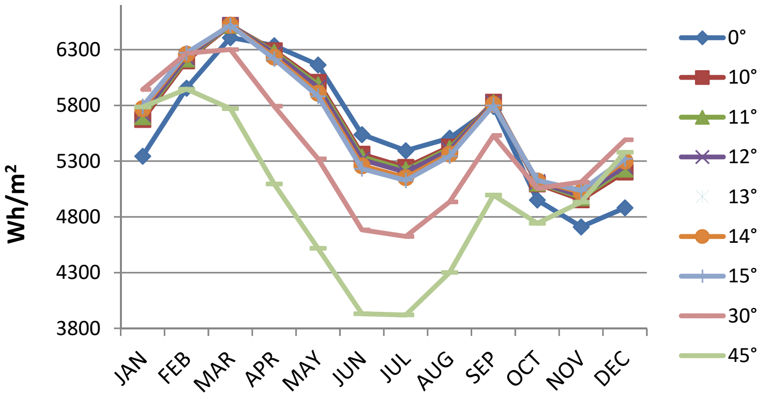

Fig. 3 Month-wise average solar radiation at different tilt angles

appliances to be powered and their quantity, power ratings, nominal operating voltage and number of operating hours in a day. The load required for the school building has been estimated with the help of school teachers of Malliamman durgam. Power for community load has been estimated by considering the total households, total population and the area of the habitation and the number of street lights required. Table 1 gives the details about habitations daily energy demand in terms of the type of load, quantity and ratings of proposed appliances, operating hours of each appliance and its daily energy demand. Figure 4 shows the expected hourly load profile and time of the peak power demand for the habitation.

5.4 Proposed System and Its Economic Viability

By using expressions (1) to (8), a reliable off-grid solar photovoltaic system has been sized to fulfil the load profile and daily energy demand of 63.2 kWh of the remote habitation. Results of the technical parameters of a photovoltaic system are presented in Table 2.

By using the life cycle cost analysis method, the economic viability of the proposed system has been estimated by using expressions (9) to (14) and the obtained results are given in Table 3. The cost tabulated in Table 3 is estimated by using the current market price (Indian rupees) of solar photovoltaic equipment.

Table 1 Daily energy demand of Malliamman durgam

Type of room	No. of rooms	Quantity of appliances	Appliance rating (watt)	Total watt	Operating (usage) hours/day	Total energy Wh/day
School						
Classroom	1	2	6	12	5	60
Kitchen	1	1	4	4	1	4
Toilet	1	1	4	4	2	8
Verandha		2	4	8	5	40
Laptop		1	60	60	4	240
Playground light		2	12	24	12	288
Television		1	120	120	4	480
DVD player		1	12	12	4	48
Multimedia projector (Weekly load)		1	300	300	4	80
Temple premises	2	2	6	12	4	48
Temple garden light		1	12	12	12	144
Streetlights		25	12	300	12	3600
Drinking water supply pump (1.5 HP)		1	1119	1119	4	4476
Flour mill motor	1	1	3000	3000	4	12,000
Flour mill premises	1	1	6	6	4	24
SPV plant load						
LED lighting system	2	2	6	12	5	60
Power plant area lighting		3	12	36	12	432
Fan		1	60	60	12	720
Domestic load						
Living room		74	6	444	11	4884
Kitchen		74	4	296	4	1184

(continued)

Table 1 (continued)

Type of room	No. of rooms	Quantity of appliances	Appliance rating (watt)	Total watt	Operating (usage) hours/day	Total energy Wh/day
Bathroom		74	4	296	2	592
Verandha		74	4	296	5	1480
Television		74	72	5328	6	31,968
Mobile phone		20	3	60	6	360
	Total load required			11,821		63,220

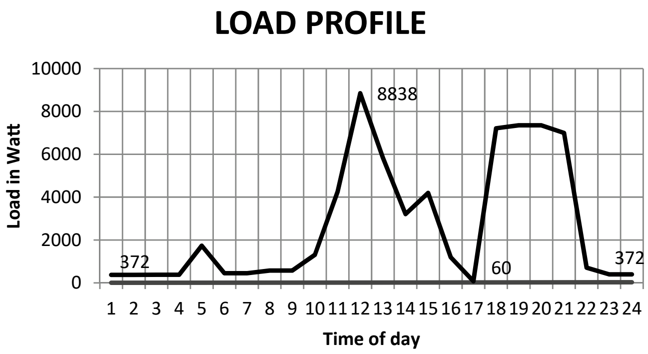

Fig. 4 Expected hourly load profile of Malliamman durgam

6 Conclusions

To electrify the Malliamman durgam habitation, a solar photovoltaic system with an installed capacity of 20 kWp has been proposed and the unit electricity cost for the proposed system has been worked out. By considering environmental benefits such as a clean development mechanism and certified emission reduction, the proposed off-grid system would generate more revenue which would further reduce the unit electricity cost of the proposed off-grid solar photovoltaic system. Socio-economically, the proposed solar photovoltaic system would increase the productivity and earnings of people by electrifying the habitation. Water pumps can be set up for agricultural purpose which will increase the yield of crops and will give more income from agricultural products. Setting up a primary health centre will help the habitants to live a better life. Four or five people will get employment at the proposed off-grid solar photovoltaic system which will help to improve their living standards. Further, the system will help to reduce the percentage of migration of habitants to nearby towns.

Table 2 Technical parameters of the proposed solar photovoltaic system

Parameters	Unit/qty
Installed capacity	20 kWp
Unit module rating	220 Wp
Type of cell	Polycrystalline
Number of modules in a string	5
Number of strings	18
Weight of module	19 kg
Field junction box, 1 for each 6 strings	3
Main junction box	1
Battery pack capacity	1850 Ah
Cell voltage	2 V
PV module open circuit voltage	36.42 V
Battery unit capacity	1850 Ah
Total number of batteries	60
Inverter nominal current	49 A
Inverter overload current	148 A
Inverter input voltage range, DC	120 V–180 V
Inverter output voltage range, AC	220 V–240 V
Power factor	0.8
Annual energy generation	37,960 kWh

Table 3 Economical parameters

Particulars	Cost in INR
Life cycle capital cost	5,024,352.00
Life cycle O & M cost	1,418,820.00
Life cycle nonrecurring cost	4,065,090.00
Life cycle cost	10,508,262.00
Unit electricity cost without CFA	13.84
Unit electricity cost with CFA	11.70
Available CFA	1,620,000.00

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Multi-objective Weighted-Sum Optimization for Stability of Dual-Area Power System Using Water Cycle Algorithm

CH. Naga Sai Kalyan, Chintalapudi V. Suresh, and U. Ramaniah

1 Introduction

With the existence of rapid industrialization in the current scenario, the demand for electrical energy is continuously increasing. To meet this ever-changing load demand, more number of electrical utilities are participating and becoming the interconnected power system that is more complex. The electric utilities are sub-grouped as control areas that connect the other areas through transmission lines named tie-lines. Whenever a small load change occurs in any of the control areas, then there will be considerable disturbances in parameters of the system such as frequency and tie-line power that make the entire power system unhealthy. Moreover, the efficacy and stability of the power system strongly depend on governing of frequency variations and tie-line power flow among control areas within prescribed limits. This task can be accomplished by employing balance among demand and generation through load frequency controller (LFC). From the above perspective, an efficient and robust LFC control technique is necessary to nullify the effect of load variations on the system parameters.

Thus, researchers are striving to implement various novel control strategies for LFC of power systems. In [1], an extensive analysis of LFC strategies on different power system models is presented. It is noticed that the research work is critically concentrated on designing of LFC controller based on optimal soft computing methods to enhance the performance of dual-area, three-area conventional power system models [2], and traditional system with renewable integration of harnessing power through wind and solar PV [3]. Traditional controllers of PI/PID [4], modified PID [5] and degree of freedom (DOF) controllers [6], intelligent fuzzy [7] and neural network-based (NN) controllers [8], fractional order (FO) FOPI/FOPID

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[9] etc. are extensively reported in the literature. Moreover, the intelligent fuzzy controller involves a lot of approximations and assumptions in the selection of membership functions and NN-based controllers that requires more the number of layers with nonlinear threshold function to get the best outcome limiting the application boundary. Moreover, the FO-based controllers possess extra control knobs that need to be varied to get control over the system performance. Because of the operational efficacy and simplicity in design, traditional PID controller is widely accepted and implemented by researchers in various studies. The structure of PIDD is very much closure to that of traditional PID, except for the accession of double-derivative gain which facilitates dampening the parameter deviations further. Though PIDD controller is implemented in the study of LFC [10] and is limited to a single-objective function only, but still it needs more extensive analysis in the domain of power system control and optimization considering multi-objective weighted-sum optimizations. This motivates the author to implement PIDD in this work.

Moreover, the selection of an optimization algorithm to find the optimal gains is also having equal importance as that of controller design. Various global optimization algorithms like grey wolf optimizer (GWO) [2], grasshopper optimization (GO) [5], dragonfly algorithm (DA) [6], imperialist competitive algorithm (ICA) [7], sine–cosine algorithm (SCA) [9], ant lion optimizer (ALO) [10] and some hybrid (h) algorithms of artificial electric field (HAEFA) [11], firefly and pattern search (hFA-PS) [4] etc. are implemented. Further, water cycle algorithm (WCA) is one of the latest and simple optimization techniques which are proven to be fitted for the application of different engineering optimization problems. WCA requires very few initial parameters and involves less computational burden, which encourages the author to implement this work.

The contributions of this paper are:

(a) Dual-area hydro-thermal system is designed in MATLAB/SIMULINK.
(b) PIDD optimized with WCA algorithm is implemented as secondary regulator whose efficacy is deliberated by comparing with PI/PID and PIDN controllers.
(c) Weighted-sum multi-objective function is formulated to enhance WCA-based PIDD controller performance.
(d) The proposed control strategy performance is showcased by comparing with other approaches reported in recent literature.

2 Test System Model

Dual-area power system model of the hydro-thermal system, possessing the turbine structures of non-reheat shown in Fig. 1, is considered for investigation. Each area is having a rated power of 2000 MW with 1000 MW nominal loading and all the generators in each area are assumed to be in coherent. An analysis is performed on the power system by impressing a step load change of 1% SLP on only area-1. The nominal parameters of the system are directly considered from [4], and are designed in the version of MATLAB/SIMULINK (R2016b).

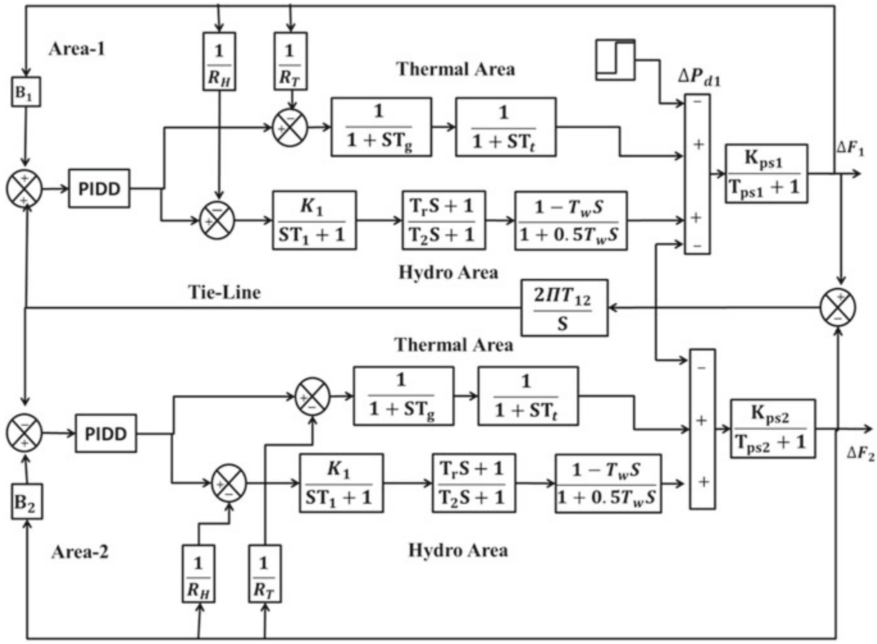

Fig. 1 Considered dual-area system for investigation

3 Controller and Objective Function

The robust performance of classical PID controllers against wide operating ranges got the researcher's attention to implement in various power system studies. The structure of a PIDD controller almost resembles the classical PID, except for the addition of double-derivative gain. By adding the DD gain to the regular PID controller, the capability of regulating undershoots is improvized, thereby the stability of the system can be enhanced. The PIDD controller structure is given in [10]. Area control error (ACE) is given as input to the controller and the controller output is modeled as

$$U(S) = ACE * (K_P + \frac{K_I}{S} + K_D S + K_{DD} S^2) \quad (1)$$

Weighted-sum of multi-objective function is formulated to find the PIDD controller gains with the help of WCA. The multi-objective function comprises the combinations of error squared over integral (ISE) and absolute error multiplied with time over the integral (ITAE) objective functions. However, ITAE is more sensitive than other performance indices. This means small deviations in controller parameters might worsen the system performance. Thus, it is always desired to permit slight deviation from optimal settings. Depending on this logic, the ISE index is attached with ITAE in the fashion of weighted-sum of multiple objective functions. Moreover, ISE focuses on penalizing the magnitudes of both over and under shoots.

$$J_{ISE} = \int_0^{T_{sim}} (\Delta F_1^2 + \Delta P_{tie,12}^2 + \Delta F_2^2)dt \quad (2)$$

$$J_{ITAE} = \int_0^{T_{sim}} t * (\Delta F_1 + \Delta P_{tie,12} + \Delta F_2)dt \quad (3)$$

$$J_{Multi.Obj} = W_1 * J_{ISE} + W_2 * J_{ITAE} \quad (4)$$

The weights W_1 and W_2 must satisfy the following equation:

$$\sum_{i=1}^{N} W_i = 1, \qquad W_i \succ 0 \quad (5)$$

4 Water Cycle Algorithm (WCA)

WCA is a novel method generally used to solve nonlinear engineering problems with constraints. In WCA, the sea is the global best value, and the river or streams as initial population meets the sea at the last. It has the potentiality to trace the minimum or maximum value of the function accurately with a high convergence rate. For a problem with N_{var} variables and every raindrop (RD) is an array of $1XN_{var}$ is a solution to the problem.

$$RD_i = X_i = [x_1, x_2 \ldots\ldots\ldots x_{Nvar}] \quad (6)$$

$$\text{Population } RD = \begin{bmatrix} RD_1 \\ --- \\ RD_i \\ --- \\ RD_{N_{POP}} \end{bmatrix} \quad (7)$$

The number of RD is represented with N_{POP}, and later calculate the cost of every RD using the cost function.

Flow of streams into river and flow of river into sea

At last, every stream and river must join with the sea by the following equations:

$$POS_{stream}^{new} = POS_{stream} + rand() * C * (POS_{river} - POS_{stream}) \quad (8)$$

$$POS_{river}^{new} = POS_{river} + rand() * C * (POS_{sea} - POS_{river}) \tag{9}$$

where rand () indicates the random number generated in between 0 and 1, C indicates the value between 1 and 2. If the result produced by the steam is more beneficial than the river then the position (POS) of the stream and river is exchanged. The same logic is applicable for the river and the sea.

Evaporation and raining

The evaporation and raining loop are introduced in WCA to avoid the solution getting trapped into local minima. The procedure of evaporation terminates if

$$|POS_{sea} - POS_{river}| < d_{max} \tag{10}$$

$$d_{max}^{new} = d_{max} - (d_{max/}/max.iteration) \tag{11}$$

The process of raining starts immediately after the termination of the evaporation process

$$POS_{stream}^{new} = POS_{sea} + \sqrt{U}\, X\, rand(1, N_{var}) \tag{12}$$

The parameter 'U' indicates the search rate nearer to the sea. The main loop will get terminated when the searching process reaches maximum iteration and then the global best solutions are displayed. The flowchart of WCA is given in Fig. 2 [12].

5 Simulation Results

The behavior of the power system is analyzed by impressing 1% SLP load change on area-1. The WCA is implemented to retrieve the regulator parameters for a maximum of 50 iterations and a population count of 30.

5.1 Case 1: System Responses Under Various Controllers Subjected to ITAE Objective Function

In this case, the dynamics of dual-area system are analyzed by considering various traditional controllers such as PI, PID, PIDN and PIDD one at a time optimized with WCA algorithm subjected to ITAE function. The system responses for this case are rendered in Fig. 3, and the respective settling time (T_S) is noted in Table 1. Elucidated from Fig. 3 and Table 1, it is obvious that the responses under the supervision of