Renewable and Sustainable Energy Reviews 81 (2018) 756–759

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Project scheduling for constructing biogas plant using critical path method

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ARTICLE INFO

Keywords:
Biogas plant
Construction
Critical path method
Project management
Scheduling

ABSTRACT

Population growth and technological progress have led to increased energy demand. While fossil fuels are currently the main energy resources, they are limited and their combustion causes environmental pollution. Therefore, alternative energy sources should be considered. For this purpose, biogas can be a convenient renewable energy option, which can be produced from organic wastes, e.g. livestock manure and rural wastes which are widely available and accessible. Furthermore, it is considered as a convenient option for rural areas that do not have access to any gas networks. However, managing a large-scale biogas plant construction project demands many coordinated activities with varying durations and involves numerous dependencies. Therefore, this study focuses on application of planning and scheduling for analysis of biogas plant construction project using critical path method (CPM). The results revealed that the minimum completion time of constructing a 50 m^3 biogas plant with fixed dome in Iran would be 38 weeks if no delays postpone the project steps. Also, a project network is proposed to show the relationships between the activities and monitor the progress of the project.

1. Introduction

Fossil fuel resources are severely limited and their combustion is a major source of environmental pollution [1]. Therefore, managers in the field of energy are seeking alternatives to fossil fuels and have considered biogas as a viable alternative source of energy [2]. Anaerobic digestion is one of the ways of converting biomass to biogas [3,4]. Every year, large amounts of livestock manure discharges and rural waste materials are produced worldwide, which can generate environmental pollution. Also, on one side, the human population is to face fossil energy depletion soon [5] while, on the other side, biomass is abundant and the operation of biogas systems is quite simple. So, it is intelligent to use animal wastes in order to produce biogas and hence reduce pollution.

In this way, generation of biogas from such residual streams can add value to them and create noticeable opportunities for development of agricultural and forestry sectors of rural areas. Therefore, biogas production plants in rural areas can gain profits even if they be not supported by any external sector. Furthermore, the plants can get more credits through treating waste, reducing emissions and producing fertilizers [6]. Another factor that can affect the economy of biomass plant establishment is the kind of biomass or feedstock that is going to be used for biogas production and its availability. For example, in rural areas, agricultural residues, manure and crops are more abundant. It is noteworthy that, in the case of using manure, the plant can impact the environment positively since it can treat manure and reduce methane emission. Biogas technology, therefore, benefits societies by alleviating problems with rural wastes and livestock manure, and generating a renewable energy source [5].

Regardless of the type energy resource, an effective management is crucial. Managing a large-scale project needs to coordinate many activities with variable duration and multiple dependencies. In other words, scheduling issue is a frequent task in the control of various systems such as construction processes and careful planning, before the start of the project, is very important. Specifically, when the energy source is biogas, its plant establishment is an expensive and time-consuming project. So that the importance of project management, in this case, is obvious [7,8].

Many different techniques and tools, e.g. Guntt chart, Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), have been developed to support an improved project planning. These tools are used seriously by a large majority of project managers to identify critical activities and calculate the minimum time required for project completion [9–11]. Among these methods, most traditional scheduling techniques employ Gantt chart. Although this method is still a valuable tool, its application is limited for scheduling large-scale operations. In particular, the bar chart fails to delineate the complex interactions and precedence relationships existing among the project activities. Network-based procedures of PERT and CPM are well known and widely used to assist managers in planning and controlling both large and small projects of all types including construction, research, development projects and many others [12–14]. Also, network models

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http://dx.doi.org/10.1016/j.rser.2017.08.025
Received 4 May 2016; Received in revised form 26 May 2017; Accepted 10 August 2017
1364-0321/

have been used as planning and project controlling techniques in agricultural projects [15–17]. CPM uses a network to coordinate activities, develop schedules and monitor progress of the projects [18,19]. In fact, it is a step-by-step project management technique that identifies activities on the critical path. It is an approach to project scheduling that breaks the project into several work tasks, displays them in a flow chart and then calculates the project duration based on estimated durations for each task. It defines tasks that are critical, time-wise, in completing the project.

CPM has been used extensively to calculate operation parameters including earliest starting time, latest starting time, earliest finish time, latest finish time, maximum available time and slack time [20,21]. However, schedule delays may occur in many of these construction projects and effective project management techniques become important to ensure successful project performance. So that, a poor strategy can shift all profits towards economic loss [22]. Management of construction projects involves planning tasks from a large number of disciplines, which requires different pieces of information at various times. Therefore, a noticeable body of complicated information would be produced that should be efficiently managed. A management solution is application of network analysis which has significant influence on planning and controlling large projects in many fields, such as construction. The project duration will be no longer than the longest path through the network. As a consequence, the total time elapsed for project completion is equivalent to the length of the critical path, i.e. the longest path through the network. Also, the corresponding activities are called the critical activities. Any delay in the critical activities retards the project completion overall time and the project should be managed to avoid delays in any of these activities.

In this regard, this study attempts to apply project scheduling for establishing biogas plant with fixed dome in large size (50 m^3), by critical path method by employing WinQsb software.

2. Materials and methods

The study was carried out in Iran, in 2015. Statistics and information about the region circumstances, soil properties and quantity of input substrate were collected through direct observation, discussion with farmers and experts and also using the statistical data of Ministry of Agriculture [23] and Statistical Center of Iran [24].

Planning of biogas plants is basically not easy since considerable data is required before the engineering design and activities can be started. At first, the project has to be broken into several work tasks that consist of primary studies (type of input substrate [25–27], weather condition, local circumstances, soil properties and quantity of input substrate), coordination and negotiation with farmers, selection of site and layout of the plant, marketing and financial support, purchase of construction materials and tools, labor hire, ground excavation, construction of biogas digester, construction of inlet pit, construction of outlet chamber, construction of gas pipeline, loading raw materials and biogas production, technical review and reloading with improved variables, farmer training and documentation. For example, about site selection, the chosen area should be adequate to accommodate all units of the plant; the location of the plant must be at least 20 m away from the water sources such as wells, springs, tube wells etc. to avoid possible contamination of water sources; and edge of the plant foundation should be at least two meters away from houses or any other building to avoid the risk of any damage being made to them. Fig. 1 shows the layout of the biogas plant with fixed dome.

Depending on the input substrate and procedure, which is applied to construction of the biogas plant, the duration of each activity is determined. Then, the estimated duration for each activity is used to calculate the project duration. In the next step, immediate predecessors have to be defined for each activity. Immediate predecessor of activity y is activity x that must be completed no later than the starting time of activity y. When an activity has more than one immediate predecessor, they must all be completed before the activity initiation. Also, the project network is proposed to illustrate the connections between the activities and monitor the project progress.

2.1. Critical path method calculations

In order to determine the critical path, five parameters are considered for each activity including the earliest start and finish times, the latest start and finish times, and slack time. For a list of activities required to complete a project with duration of each activity and dependency of activities on each other, critical path scheduling for an activity-on-node network can be formulated, mathematically. Node display method for critical path calculation of activity-on-node is presented in Fig. 2.

$ES(i)$ is defined as the earliest start time for activity i, $EF(i)$ is the earliest finish time for activity i, $LS(i)$ is the latest start and $LF(i)$ is the latest finish time for activity i. The relevant calculations for the node numbering algorithm, the forward pass (runs from the first to the last node in the network) and the backward pass (runs from the end node back to the first node in the network) are presented as follows:

Step 1: the starting activity will be numbered as 0.
Step 2: the next number will be assigned to any unnumbered activity whose predecessor activities are already numbered. Step 2 will be repeated until all activities are numbered.

2.1.1. Forward pass calculation

The earliest start and earliest finish times for each activity within the network are computed by forward pass. During the calculations, constraints on finish times are concerned through recognizing the minimum finish time and then subtracting the activity duration (D_j). Moreover, a default earliest start time of day 0 is also insured for all activities. In the next step, the earliest finish time of each activity is specified.

Step 1: $E(0) = 0$.
Step 2: For $j = 1,2,3, \ldots, n$ (where n is the last activity), $ES(j) =$ maximum $\{EF(i)\}$
Step 3: $EF(j) = ES(j) + D_j$

2.1.2. Backward pass calculation

Calculations of the backward pass follow a procedure similar to the forward pass but they focus on the latest finish and start times instead of the earliest times. During the backward pass computation of the latest finish time, the latest start time is defined to be consistent with the precedence constraints on the activities' start times. Therefore, the computations involve minimizations over all activities (j) that have (i) as their predecessor. Also, at this point, feasibility of the activity schedule can be checked and imposed. The rule is that the activity schedule is not possible if the late start time is less than the early start time.

Step 1: Let $L(n)$ equal to the required completion time of the project.
Note: $L(n)$ must equal to/exceed $E(n)$.
Step 2: For $i = n-1, n-2, \ldots, 0$, $LF(i) =$ minimum $\{LS(j)\}$
Step 3: $LS(i) = LF(i) - D_i$

2.1.3. Slack time calculation

The forward and backward pass calculations on each activity give several activity time values which include the earliest start time, the latest start time, the earliest finish time and the latest finish time, directly. In addition, their calculations indirectly result in the activity slack time, i.e. the difference between the earliest and latest time of the activity. In fact, slack time is the maximum time interval that the activity can be delayed without retarding project completion [28,29]. Slack times are calculated as: