

# Standalone Smart Irrigation System: An Analysis of Reliability Incorporating BPNN Technique under Various Failures

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Received April 8, 2022; Revised July 20, 2022; Accepted August 20, 2022

## Cite This Paper in the Following Citation Styles

(a): [1] Nitin Kumar Sharma, SachinKumar, Pradeep Kumar Yadav, Ekata, "Standalone Smart Irrigation System: An Analysis of Reliability Incorporating BPNN Technique under Various Failures," *Universal Journal of Agricultural Research*, Vol. 10, No. 4, pp. 417 - 435, 2022. DOI: 10.13189/ujar.2022.100411.

(b): Nitin Kumar Sharma, SachinKumar, Pradeep Kumar Yadav, Ekata (2022). *Standalone Smart Irrigation System: An Analysis of Reliability Incorporating BPNN Technique under Various Failures*. *Universal Journal of Agricultural Research*, 10(4), 417 - 435. DOI: 10.13189/ujar.2022.100411.

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**Abstract** Observing the huge requirements of water and energy for traditional irrigation and contracting resources, the utility of a smart irrigation system has become necessary. A system that is capable of saving water depends on renewable energy resources for power requirements and runs automatically. Water-saving automatic irrigation systems powered by renewable energy could be a solution to India's rising demand for energy and water. In the current paper, the author has proposed an analysis of a standalone smart irrigation system for its reliability and functional behaviour under various operational events of failures and repairs. The authors have implemented an intelligent computational method because of the increased degradation in system function due to the complex structure of the proposed irrigation system. The system's mathematical formulation is stated in terms of neural networks, and a back propagation neural network technique is applied for fast and comparatively better outcomes. The author has determined state probabilities and other reliability parameters by means of neural networks in the proposed smart irrigation system. To improve the accuracy and consistency of reliability parameters, a Feed Forward Back Propagation Neural Network (FFBPNN) is applied. FFBPNN's learning mechanism can optimize the values of parameters by modifying neural weights. The MATLAB codes are used by the authors to demonstrate the numerical examples, and

iterations are repeated until the precision in error tends to 0.0001. The sensitivity and cost of the system are also analyzed, which can help in managing the real-time operations of the system.

**Keywords** Back Propagation Algorithm, Environmental Failure, Neural Networks, Reliability, Renewable Energy System, Smart Irrigation System, Moisture Sensors, Sensitivity Analysis

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## 1. Introduction

The development of the agriculture sector plays an important role in supporting the economy of India. The development of agriculture depends on various factors like the supply of electricity, rainfall, water availability, fertilizers, climate conditions, etc. To increase the availability of water, there is a need to improve the utilisation and preservation of water by decreasing wastage. Studies say that sustainable production of crops uses nearly 70% of global freshwater for irrigation [1]. The contribution of irrigated areas to global croplands and global food production is around 18% and 40%, respectively [2]. It is also reported that out of all the irrigation methods practiced globally, 40% are not

sustainable as they reduce groundwater stocks and/or natural flows [3].

### 1.1. Need and Types of Irrigation

Our country's rainfall is determined by the monsoons. Agriculture is controlled by rainfall, yet it is often referred to as "monsoon gambling" since monsoon rainfall is unpredictable, erratic, and unbalanced. The temperature

starts rising from February, touches a high in May/June, then follows a decreasing trend due to the start of the monsoon in June (Fig. 1A). In India, 80 percent of the yearly rainfall falls in just four months, from mid-June to mid-October and duration is nearly the same for Delhi-NCR area in North India (Fig. 1B, 1C). During this period, atmospheric humidity stays high and rain keeps the soil constantly moist.

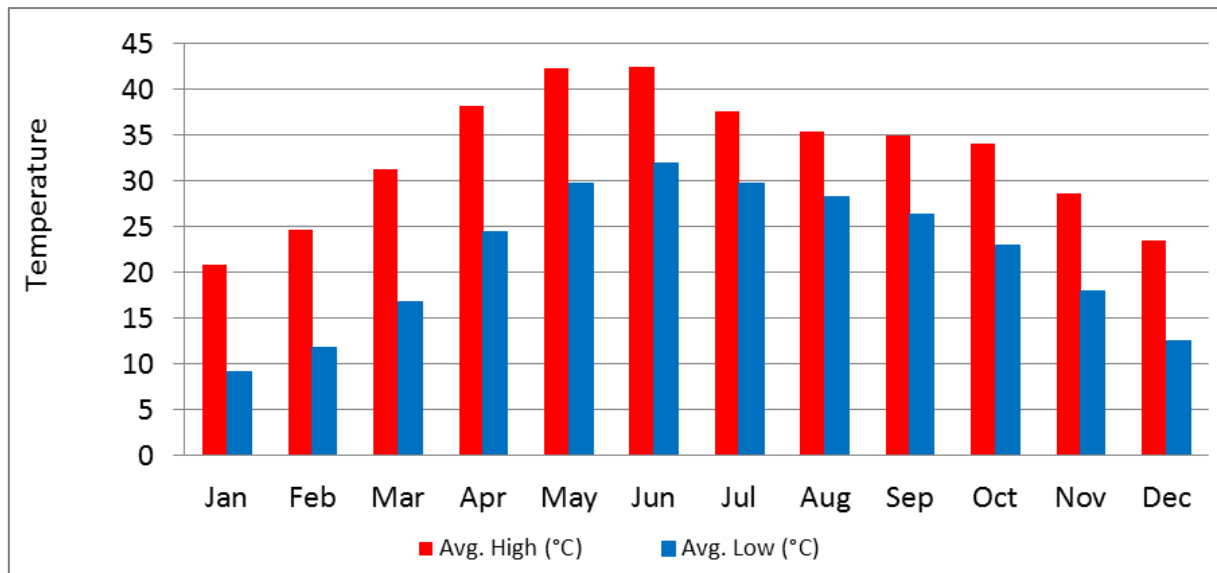


Figure 1A. Annual Temperature Distribution

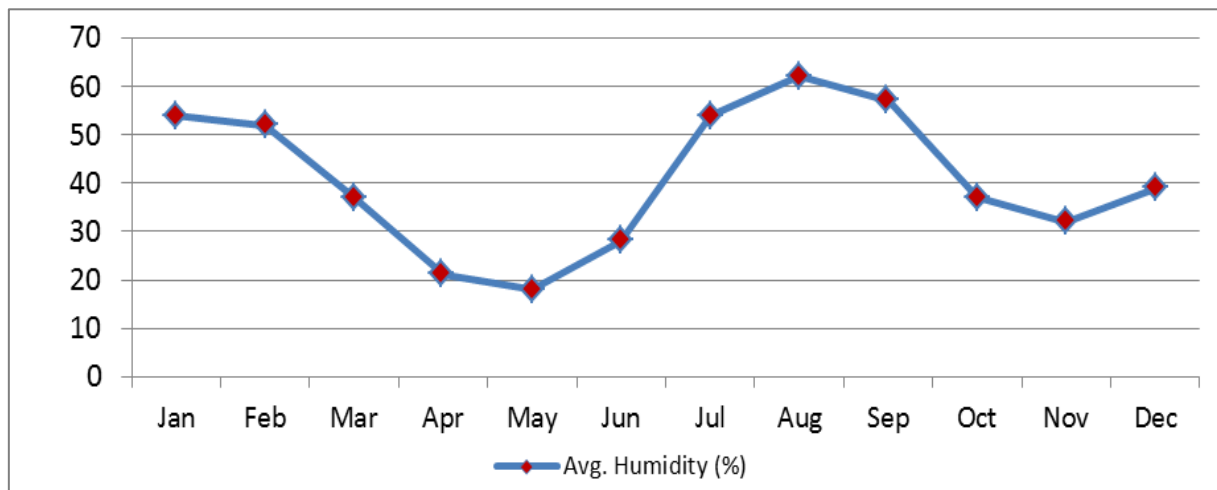


Figure 1B. Annual Humidity Distribution

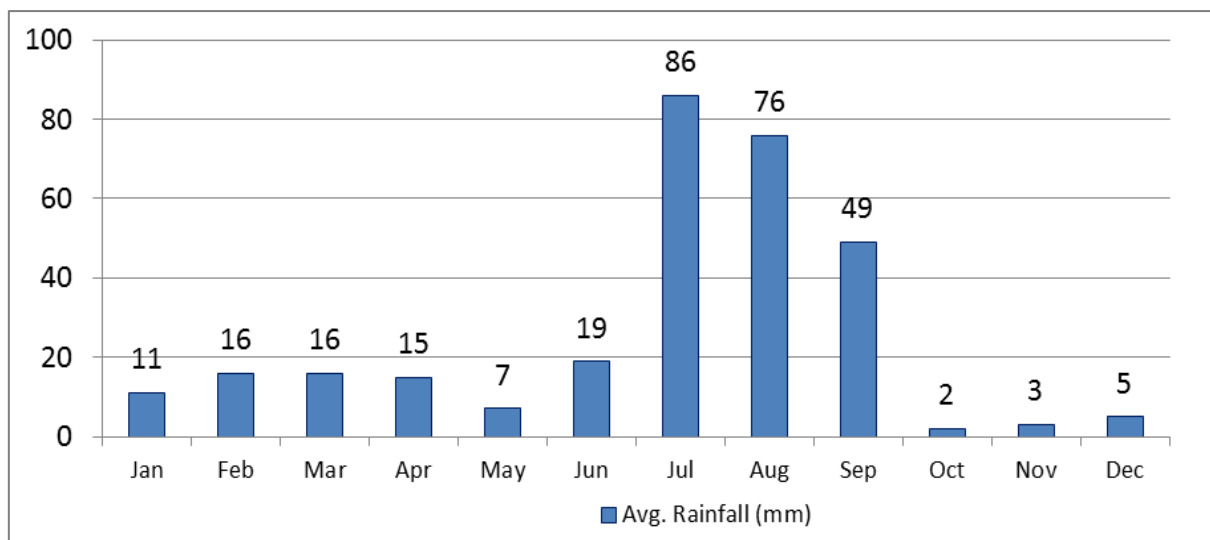


Figure 1C. Annual Rainfall Distribution



Figure 2. Drip System Irrigation

As a result, irrigation for agriculture fields is critical for the remaining eight months. There are several methods for irrigating croplands for various sorts of crops. The irrigation methods used by Indian farmers are surface irrigation, sub-surface irrigation, sprinkler system, and drip system (Fig. 2). A popular and conventional method is the flood irrigation method. A smart irrigation system, on the other hand, is a novel technique for autonomously irrigating croplands [1]. This procedure generates a cascade of water drops that fall one by one on the roots. It's the most efficient way to keep crops, parks, and other plants hydrated. Water flows through a supply line before being divided into relatively smaller pipelines. In these sub-pipes, specially engineered nozzles are placed. This method wastes very little water and eliminates the need for workers to irrigate. Start the engine and choose the direction from the nozzles once the farmer has determined the state of the agricultural field. When some time has elapsed, the user inspects the irrigated land, and the pump is shut off while the entire crop is hydrated.

Observing the methods described above, the wastage of water, electric power, and manpower doesn't make sense in the modern era of the internet and automation. Therefore, the Smart Irrigation System is a solution. While surface irrigation, sub-surface irrigation, and sprinkler system are typically operated in the physical presence of the farmer, a smart water management system for irrigation is one in which the entire network is operated by self-governing mechanisms, meaning it will handle the entire watering system even if the operator is physically absent from the cropland. It will alert the farmer about irrigation status and enable him to manage irrigation remotely. This approach, comparatively, does not require a large number of people and saves water because there is less wastage of water.

Adamsab et al. [4] envisioned a reliable irrigation design being developed and modernized. In addition, current technology is required, and the deployment of fourth industrial technologies such as AI and IoT has more potential to tackle this problem. They constructed and implemented an intelligent system for irrigation that is

powered by hydro and PV panels. They used free energy available at their location and minimized the wastage of water during irrigation. The battery can be charged using the electric energy produced by the hybrid renewable energy system. They designed an intelligent system for irrigation consisting of an Arduino-based controller, receivers, transmitters, sensors, etc.

Many researchers report that an automated irrigation system, powered by solar source, decreases the wastage of water if used with modern sensors and intelligent devices. These devices dispense the exact volume of water as per estimation of temperature, moisture in soil, and humidity of surroundings. Now a day, smart irrigation systems depend on the concept of the internet and IoT, which are connected with various measuring probes and sensors to automate the processes. Industries, in their R & D, focused on making irrigation more automatic and reasonable in cost [5,6]. Some researchers have reported that the use of non-conventional power sources, to fulfil the demand for power for irrigation, is increasing, which is beneficial for our environment and economy. Most traditional irrigation systems are dependent on diesel-powered engines or grid-based electricity. Both of these are costlier and are not available in remote areas for agricultural use. Sharma et al. and Khare et al. [7,8] assessed the reliability and other statistics for an electric power generation system based on a combination of PV modules, wind turbines, and a battery bank. They find that integrated green energy sources are a suitable and reliable answer for power requirements in remote areas and other projects [9]. Ekata et al. [10] analyzed the reliability and cost parameters of hybrid renewable electric power systems and stated that repair costs rise with time, but expenditure may be compensated by selling surplus power to the grid, which makes it more financially stable. Also, oil fuels are harmful to the environment, and the oil sources are exhausting day by day. Solar radiation is a sufficiently available source of energy in comparison with hydropower. It is the most suitable option for the energy crisis, and by using it for irrigation in green fields, it will not be harmful for surrounding as it is eco-friendly too. But, a huge gap can be observed in the development and establishment of solar-hybrid power systems in this sector in terms of cost and availability [11,12,13]. But constant efforts are being made by scientists and industries to encourage the usage of solar panels and other hybrid power sources in irrigation and other sectors.

Hybrid-powered Smart Drip/Sprinkle irrigation systems are increasing in trend because they are beneficial in many ways as they don't need extensive manpower, save energy as they don't run idle due to smart sensors and devices, and save the volume of water by perfect measurements of requirements. The saved water can be used to serve the colonies nearby [13]. The increasing shortage in water resources has become a challenge in the sustainable development of farming based on traditional irrigation [14]. Also, the extreme and frequent climate problems and

global warming have worsened the scenario and raised the level of concern [15]. Many researchers reported that some other factors, like the large migration of people from villages toward cities, urbanization, and unavoidable and speedy industrialization, have increased the dependence of water on natural water resources. Therefore, the availability of water has reduced gradually due to the fast increase in water supply to industries and urban areas. This part of water is compensated by the withdrawal of agricultural water as farmland irrigation accounts for around 70% of water withdrawals and over 80% of water consumption [16].

Raghuvanshi et al. [17] presented their work on the reliability of the stand-alone photovoltaic water pumping system. They calculated various reliability parameters like unavailability, failure rate, repair rate, etc. To evaluate these reliability parameters, they applied Markov model and frequency-duration techniques because these techniques are applicable for types of systems repairable and non-repairable. Karthikeyan and Suresh [18] suggested various benefits of automatic drip irrigation, such as optimal use of available water, comparatively lower evaporation losses, no soil erosion, low labour cost, and fertiliser solutions supplied to plant roots directly. Another important benefit of drip irrigation is that it can also be used in an uneven landscape. Farmers having large landholdings are satisfied by drip irrigation as a one-time investment is not a big deal for them, but marginal and small farmers still follow traditional methods.

RAE ZH Aliyev et al. [19] investigated the reliability of an automated watering systems for irrigation and suggested reliable devices must be used for uninterrupted operations. They also stated that the problem of reliability is a technical and economic task as well. They defined reliability as the property of equipment or systems to execute defined activities and keep them working for the requisite duration of time. For activities in organizations, they threw light on the fact that to avoid failures, preventive maintenance is the main issue, and its timing is also more important.

Wenju et al. [20] proposed a smart irrigation system based on Long Range (LoRa) technology. The data is transmitted from the irrigation node to the cloud through LoRa gateways via wireless transmission. In this technique, users can control systems remotely through a mobile user interface. Resultant Experimental data shows that the system performs reliably in terms of both transmission distance and energy consumption.

Chandan kumar sahu [21] presented a cost-effective prototype of an automatic irrigation system which is useful in remote zones. The analysis of experimental data exhibits that the prototype can control the irrigation motor automatically by observing the reading of the soil moisture sensor. He proposed that the prototype is beneficial for farmers as it requires less human intervention and saves energy and water as well.

R. Santhana Krishnan [22] focused on higher accuracy

in the usage of water for irrigation by implementing fuzzy logic. In their experiment, they simulated and compared the results, and it is verified that smart irrigation is more effective in the optimal use of manpower, electric power and water. A user acknowledgement system, based on Mobile (GSM), is used to communicate with a user for remote control of the system.

B. Keswani et al. [23] suggested a precision automatic agriculture system to optimize revenue and minimized the effect on the environment. They used IoT-based Wireless Sensor Network framework which is composed of various soil and environmental data sensor probes for moisture, temperature, humidity, CO<sub>2</sub>, daylight intensity device, etc. Fuzzy logic weather model and neural network techniques implemented to control and command various situations occurred during uniform irrigation of farm.

In a case study of irrigation in Australian croplands, The authors observed the unsustainable use of irrigation water in harvesting crops at the cost of the environment. Furthermore, their research revealed that utilising groundwater for irrigation has a negative impact on the ecological water flows, but using surface water for agriculture is somewhat more ecologically sustainable, more reliable, and shows a significant level of profit in economic water profitability [24].

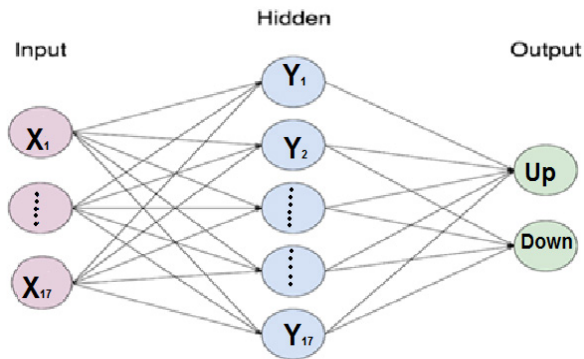


Figure 3. Neural Networks Structure

In 1965, a functional multi-layered network was introduced by Ivahnenko and Lappa in a paper, but earlier, in 1943, Walter Pitts (mathematician) and Warren McCulloch (neurophysiologist) designed a computational model of it. This network is inspired by the neurological system of the human brain and is well-known as an artificial neural network. As a processing unit, neurons are connected by synaptic weights to create a neural architecture. Here, a multi-layered architecture, with input, hidden, and output layers, is used to determine the results

of the mathematical model of the standalone smart irrigation system, (see Fig. 3), firstly inputs given to the first layer, referring to the problem, hidden layer updates the weights, and the output layer provides optimal results for the problem.

Neural networks (NN) become more dynamic and predictive for new outcomes by training through experience and error minimizing capability [8]. Reports suggest that optimization of power generation is possible through optimization techniques based on AI (artificial intelligence approach). In the current paper, a reliability model incorporating neural architecture is presented to study a standalone smart irrigation system. For the optimization of reliability indices like reliability, sensitivity, profit function, etc. some numerical examples are exhibited. Therefore, the paper is divided into 8 sections, discussing the literature survey in the introduction, the system description of the proposed model, assumptions, important notations, formulation of the mathematical structure of the irrigation model, the solution of the mathematical model, in which analysis of cost and sensitivity is discussed, and finally conclusion is the last section.

## 2. System Description

In traditional method of irrigation in agriculture like manual flooding, a large amount of electric power and water are required for irrigation of crops, but it is difficult to arrange this much amount of power and water in some remote areas. Also, if a farmer somehow arranges it, then he wastes too much due to poor management. Therefore, it takes more human intervention, labor, money, and time. In the current paper, the author has discussed the reliability of a standalone smart irrigation system. This system produces electric power using PV (solar power), and surplus charge is stored in a battery bank for backup in an emergency. The power module supplies electric power to the water supply module, where the pump extracts water from the bore well and sends it to the tank and irrigation network in a smart manner.

It is an eco-friendly method for irrigation that provides almost free water supply for irrigation after a one-time initial investment. The power controller unit manages electric power while the smart device with an intelligent controller controls the whole water irrigation system. For optimised utilisation of water and electric power, various sensors have been placed to collect and transmit the necessary data from the irrigation field and surroundings.

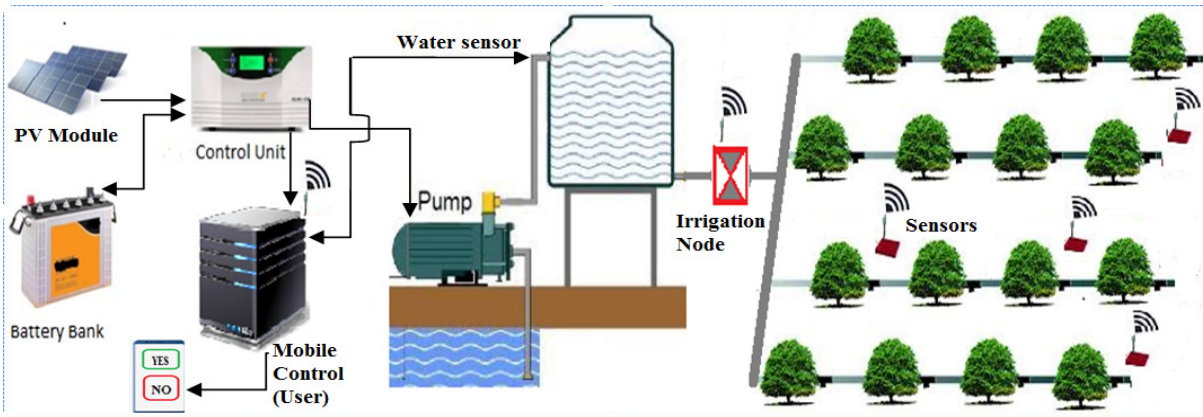


Figure 4. Block Diagram of Standalone Smart Irrigation System

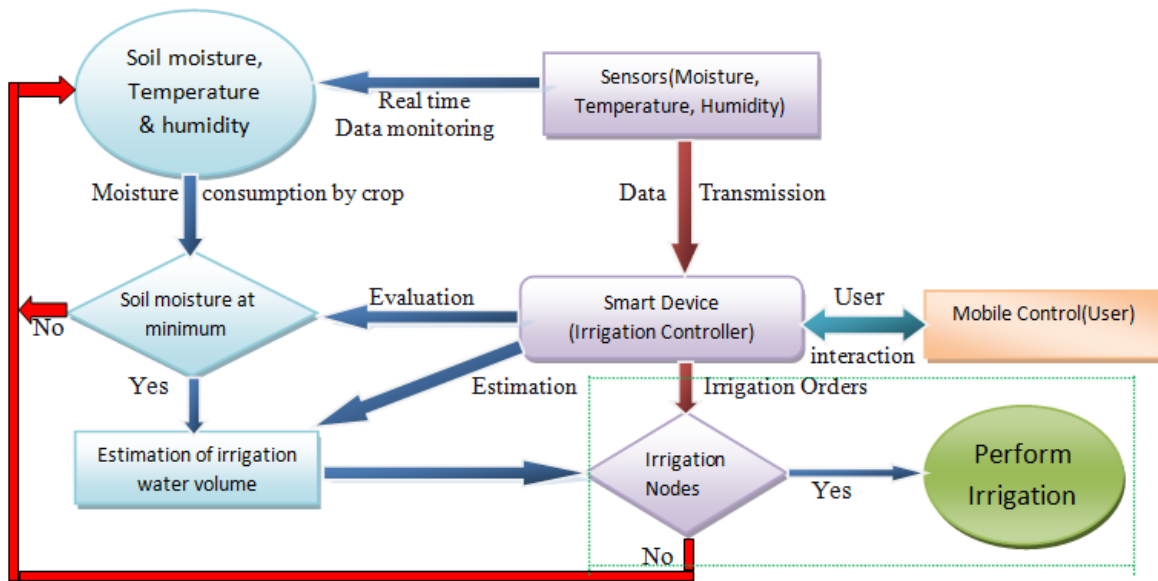


Figure 5. Logical Flow of standalone smart irrigation system

The proposed system has 4 major modules with 9 units in total (Fig. 4) and the logical flow of system depicted in Fig. 5. These subsystems are:

### 2.1. Power Module

This module consists three units namely Photovoltaic panels, battery bank and power control unit. Photovoltaic panels absorb the sunlight and convert it into electric charge. Photovoltaic panels are connected with control unit which is also connected with battery bank. To assure a continuous/seamless power supply, control unit is deployed to regulate it.

### 2.2. Smart device module

It consists of a trio of key intelligent devices: a central server, mobile control devices, and sensors. For analysis, YL-69 soil moisture sensors and LM393 comparator modules were positioned under various soil conditions.

Two electrodes make up the sensor YL-69. It gauges the amount of moisture in the area. The resistance of the soil to the current as it passes through the electrodes and across it yields information about the moisture content of the soil. More current will flow through the soil if there is greater water content because resistance will be lower. On the other hand, the sensor module produces a significant level of resistance when the soil moisture is low. This sensor features analogue and digital outputs. Since the Arduino Uno's Atmega 328P-PU microcontroller has an integrated 10-bit, 6-channel analog-to-digital (A/D) converter, it is able to read analogue data sent by sensors and return binary integers between 0 and 1023. Less moisture content is implied by greater production. The smart device unit uses the Arduino Uno platform and microcontroller ATMEGA328P as its controller platform. The surrounding environment of an irrigation field is sensed using temperature and moisture sensors. This data is sent to a smart device where calculations are done to estimate the water volume for irrigation. The device then decides and

sends instructions to the water supply module and irrigation nodes. Also, an internet based user information system (mobile control) used to interact with and alert the user also, so that the user can intervene remotely and control the irrigation in unexpected situations such as management of cattle, fire, and climate control [25].

### 2.3. Water Supply Module

It is a subsystem formed by two units: a water pump and a water storage tank. This module is a very important part of the system as it provides water for irrigation. The pump sucks water from natural ground water sources and pumps it into the overhead water tank, which assures a continuous water supply as and when required. The tank is large enough to store sufficient water for supply in case of power shortages or maintenance of the system. The pump and tank are both controlled and run by a smart device that continuously observes and senses the water level in the tank and operates the pump unit accordingly.

### 2.4. Irrigation Module

It is the target irrigation field where we have to supply water for irrigation of the desired crop. Here, irrigation is done through a complex network of drip lines and sprinklers. For a perfect harvesting environment, the field is monitored by wireless sensors for moisture in the soil, temperature of the surrounding atmosphere and humidity.

The sensed data is sent to a smart device, and irrigation is performed by controlling irrigation nodes deployed in the field.

## 3. Assumptions

- All the units/subsystems are in good and fully operable condition, initially.
- The state of all components is statistically independent, in the system.
- The system has a total of nine units as Photovoltaic modules, Battery Bank (Power storage) unit, power inverter/control unit, etc.
- The system performs with reduced capacity if the failure occurs either in one or more units.
- If the system is working in the degraded state then failure of power generation units or storage may provoke the failure of other units.
- The irrigation system may also suffer from complete breakdown due to failure of PV and BB simultaneously as well as power control unit.
- The working of irrigation system may also collapse by environmental failure.
- The rates of repairs and failures in the system are distributed exponentially.
- The synaptic weights are analogous to system failures and repairs.
- Subsystem(s) will perform like new after repair.

## 4. Notations

|                   |   |
|-------------------|---|
| $P_i(t)$          | Probability of $i^{th}$ state at any time t, where $i = 1, 2, 3, \dots, 11$           |
| $P_i(t+\Delta t)$ | Probability of $i^{th}$ state at time $(t+\Delta t)$ , where $i = 1, 2, 3, \dots, 11$ |
| $\lambda_2$       | Photovoltaic module failure   |
| $\lambda_3$       | PV+CU unit failure  |
| $\lambda_4$       | Battery bank unit failure   |
| $\lambda_5$       | PV+BB unit failure  |
| $\lambda_6$       | Battery bank (BB) unit failure  |
| $\lambda_7$       | CU+BB unit failure  |
| $\lambda_8$       | Sensors unit failure  |
| $\lambda_9$       | Sensors + Smart device failure  |
| $\lambda_{10}$    | Network feed(mobile control) failure  |
| $\lambda_{11}$    | Network feed(mobile control) + Sensors failure  |
| $\lambda_{12}$    | Network feed (mobile control) + Smart device failure                                  |
| $\lambda_{13}$    | Pump failure  |
| $\lambda_{14}$    | Pump + Tank failure   |
| $\lambda_{15}$    | PV+BB + CU unit failure   |
| $\lambda_{16}$    | Network feed + Sensors + Smart device failure   |
| $\lambda_{17}$    | Irrigation(Drip network) failure  |
|                   | Environmental failure   |
| $\mu_2$           | Photovoltaic module repair  |
| $\mu_3$           | (PV+CU)unit repair  |
| $\mu_4$           | (PV+BB) unit repair   |
| $\mu_5$           | Battery bank (BB) unit repair   |
| $\mu_6$           | (CU+BB) unit repair   |
| $\mu_7$           | Sensors unit repair   |

|            |  |
|------------|--|
| $\mu_8$    | (Sensors + Smart device) repair                |
| $\mu_9$    | Network feed(mobile control) unit repair       |
| $\mu_{10}$ | Network feed(mobile control) + Sensors repair  |
| $\mu_{11}$ | Network feed (mobile control) + Smart device   |
| $\mu_{12}$ | Pump repair                                    |
| $\mu_{13}$ | (Pump + Tank) repair                           |
| $\mu_{14}$ | (PV+BB + CU) repair                            |
| $\mu_{15}$ | (Network feed + Sensors + Smart device) repair |
| $\mu_{16}$ | Irrigation(Drip network) repair                |
| $\mu_{17}$ | Environmental repair                           |

### 5. Formation of the Mathematical Model

Using preliminary theory of probability, system parameters and transition states following probabilistic equations governing the behavior of the system (Fig. 6):

$$P_1(t + \Delta t) = (1 - \lambda_{24-} \Delta t - \lambda_5 \Delta t - \lambda_{74-} \Delta t - \lambda_9 \Delta t - \lambda_{12} \Delta t - \lambda_{14} \Delta t - \lambda_{15} \Delta t - \lambda_{16} \Delta t - \lambda_{17} \Delta t) P_1(t) + [\mu_2 P_2(t) + \mu_3 P_3(t) + \mu_4 P_4(t) + \mu_5 P_5(t) + \mu_6 P_6(t) + \mu_7 P_{710}(t) + \mu_8 P_{82}(t) + \mu_9 P_{930}(t) + \mu_{10} P_{10}(t) + \mu_{11} P_{11}(t) + \mu_{12} P_{12}(t) + \mu_{13} P_{13}(t) + \mu_{14} P_{14}(t) + \mu_{15} P_{15}(t) + \mu_{16} P_{16}(t) + \mu_{17} P_{17}(t)] \Delta t \tag{1}$$

$$P_2(t + \Delta t) = (1 - \mu_2 \Delta t - \lambda_3 \Delta t - \lambda_5 \Delta t - \lambda_{17} \Delta t) P_2(t) + \lambda_2 \Delta t P_1(t) \tag{2}$$

$$P_3(t + \Delta t) = (1 - \mu_3 \Delta t) P_3(t) + \lambda_3 \Delta t P_2(t) \tag{3}$$

$$P_4(t + \Delta t) = (1 - \mu_4 \Delta t) P_4(t) + \lambda_2 \Delta t P_5(t) + \lambda_5 \Delta t P_2(t) \tag{4}$$

$$P_5(t + \Delta t) = (1 - \mu_5 \Delta t - \lambda_2 \Delta t - \lambda_3 \Delta t - \lambda_{17} \Delta t) P_5(t) + \lambda_5 \Delta t P_1(t) \tag{5}$$

$$P_6(t + \Delta t) = (1 - \mu_6 \Delta t) P_6(t) + \lambda_3 \Delta t P_5(t) \tag{6}$$

$$P_7(t + \Delta t) = (1 - \mu_7 \Delta t - \lambda_8 \Delta t - \lambda_9 \Delta t - \lambda_{17} \Delta t) P_7(t) + \lambda_7 \Delta t P_1(t) \tag{7}$$

$$P_8(t + \Delta t) = (1 - \mu_8 \Delta t) P_8(t) + \lambda_8 \Delta t P_7(t) \tag{8}$$

$$P_9(t + \Delta t) = (1 - \mu_9 \Delta t - \lambda_7 \Delta t - \lambda_8 \Delta t - \lambda_{17} \Delta t) P_9(t) + \lambda_9 \Delta t P_1(t) \tag{9}$$

$$P_{10}(t + \Delta t) = (1 - \mu_{10} \Delta t) P_{10}(t) + P_9(t) \lambda_7 \Delta t + P_7(t) \lambda_9 \Delta t \tag{10}$$

$$P_{11}(t + \Delta t) = (1 - \mu_{11} \Delta t) P_{11}(t) + \lambda_8 \Delta t P_9(t) \tag{11}$$

$$P_{12}(t + \Delta t) = (1 - \mu_{12} \Delta t - \lambda_{13} \Delta t - \lambda_{17} \Delta t) P_{12}(t) + \lambda_{12} \Delta t P_1(t) \tag{12}$$

$$P_{13}(t + \Delta t) = (1 - \mu_{13} \Delta t) P_{13}(t) + \lambda_{13} \Delta t P_{12}(t) \tag{13}$$

$$P_{14}(t + \Delta t) = (1 - \mu_{14} \Delta t) P_{14}(t) + \lambda_{14} \Delta t P_1(t) \tag{14}$$

$$P_{15}(t + \Delta t) = (1 - \mu_{15} \Delta t) P_{15}(t) + \lambda_{15} \Delta t P_1(t) \tag{15}$$

$$P_{16}(t + \Delta t) = (1 - \mu_{16} \Delta t) P_{16}(t) + \lambda_{16} \Delta t P_1(t) \tag{16}$$

$$P_{17}(t + \Delta t) = (1 - \mu_{17} \Delta t) P_{17}(t) + [P_1(t) + P_2(t) + P_5(t) + P_7(t) + P_9(t) + P_{12}(t)] \lambda_{17} \Delta t \tag{17}$$

Where

$$\begin{aligned} \Phi_1 &= (1 - \lambda_{24-} \Delta t - \lambda_5 \Delta t - \lambda_{74-} \Delta t - \lambda_9 \Delta t - \lambda_{12} \Delta t - \lambda_{14} \Delta t - \lambda_{15} \Delta t - \lambda_{16} \Delta t - \lambda_{17} \Delta t) \\ \Phi_2 &= (1 - \mu_2 \Delta t - \lambda_3 \Delta t - \lambda_5 \Delta t - \lambda_{17} \Delta t) \\ \Phi_3 &= (1 - \mu_3 \Delta t) \end{aligned}$$

$$\begin{aligned} \phi_4 &= (1 - \mu_4 \Delta t) \\ \phi_5 &= (1 - \mu_5 \Delta t - \lambda_2 \Delta t - \lambda_3 \Delta t - \lambda_{17} \Delta t) \\ \phi_6 &= (1 - \mu_6 \Delta t) \\ \phi_7 &= (1 - \mu_7 \Delta t - \lambda_8 \Delta t - \lambda_9 \Delta t - \lambda_{17} \Delta t) \\ \phi_8 &= (1 - \mu_8 \Delta t) \\ \phi_9 &= (1 - \mu_9 \Delta t - \lambda_7 \Delta t - \lambda_8 \Delta t - \lambda_{17} \Delta t) \\ \phi_{10} &= (1 - \mu_{10} \Delta t) \\ \phi_{11} &= (1 - \mu_{11} \Delta t) \\ \phi_{12} &= (1 - \mu_{12} \Delta t - \lambda_{13} \Delta t - \lambda_{17} \Delta t) \\ \phi_{13} &= (1 - \mu_{13} \Delta t) \\ \phi_{14} &= (1 - \mu_{14} \Delta t) \\ \phi_{15} &= (1 - \mu_{15} \Delta t) \\ \phi_{16} &= (1 - \mu_{16} \Delta t) \\ \phi_{17} &= (1 - \mu_{17} \Delta t) \end{aligned}$$

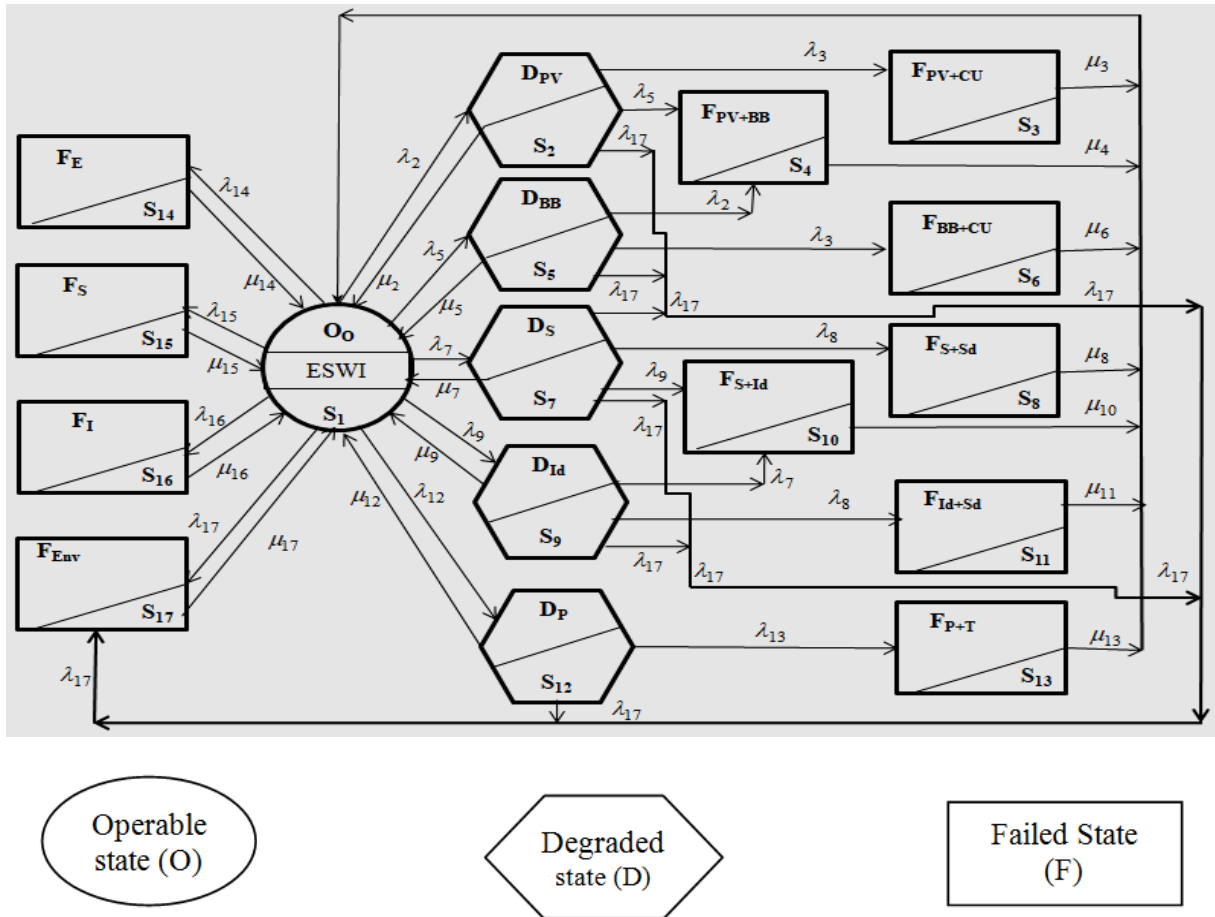


Figure 6. Transition state diagram of standalone smart irrigation system

### 6. Solution of the Model

The interconnecting input, processing, and output parameters, as well as the learning mechanism, assess the neural architecture's complicated global activity to train the

system. The BP method in NN was created in the 1970s, and it is one of the most commonly used learning algorithms for training FFNN structures. Back-propagating a gradient vector with each element defined as the derivative of an error measure for a parameter, this

approach changes synaptic weights in networks. The error signals are defined as the difference between the actual network outputs and the desired outputs. As a result, a set of desired training outputs must be inferred, and we can define back-propagation as a supervised learning process. Therefore, the supervised learning of NN can be utilized in the solving and optimization of complex mathematical models. The logical flow of back propagation feed forward neural network algorithm is explained by a schematic diagram given in Fig. 7.

Inputs,  $X_i$ , manifested in neural network structure (Fig. 3), expressed by the probabilities:

$$X_i = P_i(t) ; \text{ Where } i= 1, 2, \dots 17 \quad (18)$$

The outputs of neurons ( $Y_i$ ), in system under consideration, are represented by the probabilities:

$$Y_i = P_i(t + \Delta t) , \text{ where } i= 1, 2, \dots 17 \quad (19)$$

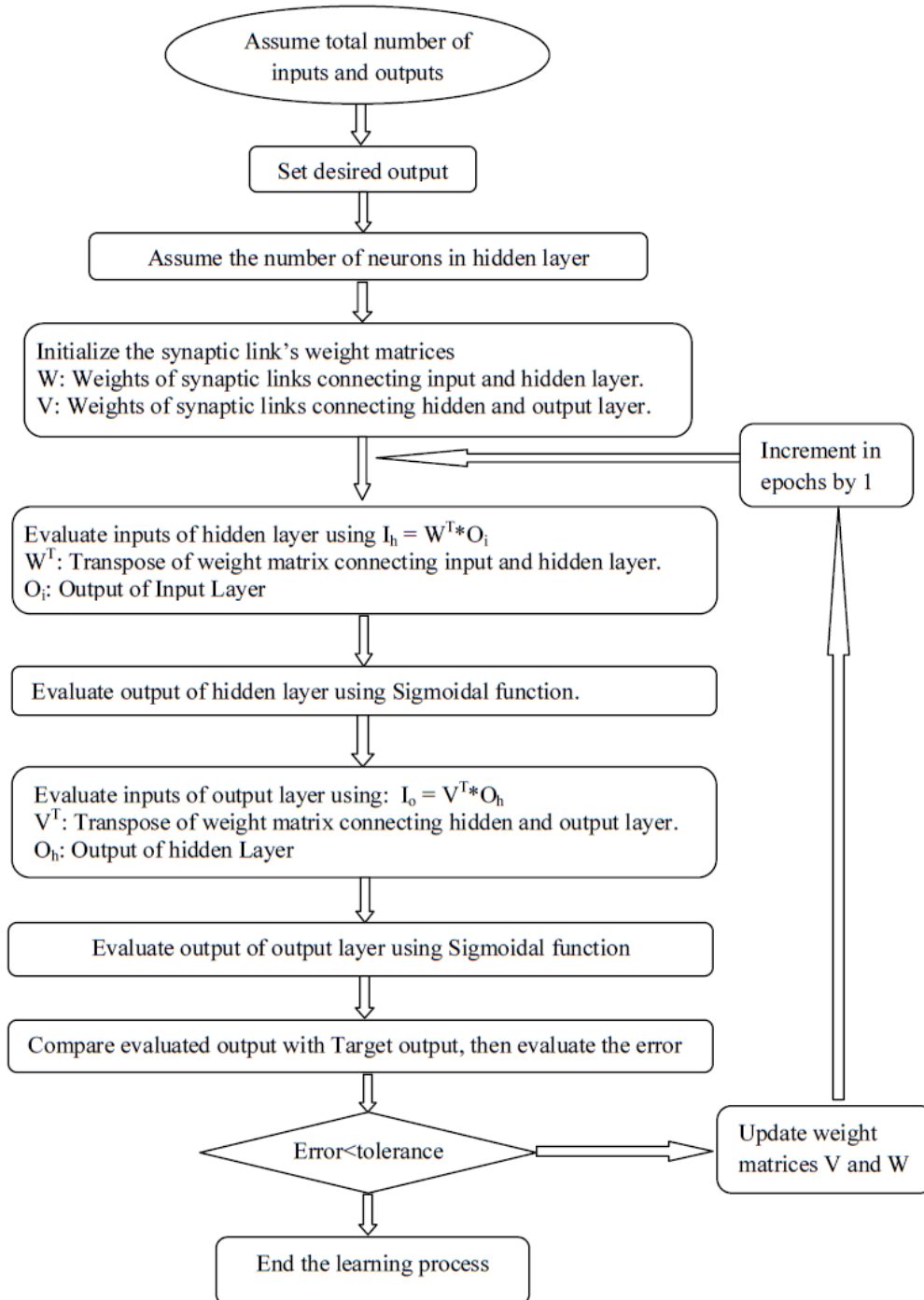


Figure 7. Logical flow of Back Propagation Feed Forward Neural Network algorithm

The matrix for neural weights among transition states of system between input and hidden layer is as follows:

$$W = \begin{bmatrix} \phi_1 & \lambda_2 \Delta t & 0 & 0 & \lambda_5 \Delta t & 0 & \lambda_7 \Delta t & 0 & \lambda_9 \Delta t & 0 & 0 & \lambda_{12} \Delta t & 0 & \lambda_{14} \Delta t & \lambda_{15} \Delta t & \lambda_{16} \Delta t & \lambda_{17} \Delta t \\ \mu_2 \Delta t & \phi_2 & \lambda_3 \Delta t & \lambda_5 \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_{17} \Delta t \\ \mu_3 \Delta t & 0 & \phi_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_4 \Delta t & 0 & 0 & \phi_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_5 \Delta t & 0 & 0 & \lambda_2 \Delta t & \phi_5 & \lambda_3 \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_{17} \Delta t \\ \mu_6 \Delta t & 0 & 0 & 0 & 0 & \phi_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_7 \Delta t & 0 & 0 & 0 & 0 & 0 & \phi_7 & \lambda_8 \Delta t & 0 & \lambda_9 \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & \lambda_{17} \Delta t \\ \mu_8 \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & \phi_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_9 \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_9 & \lambda_7 \Delta t & \lambda_8 \Delta t & 0 & 0 & 0 & 0 & 0 & \lambda_{17} \Delta t \\ \mu_{10} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_{11} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_{12} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{12} & \lambda_{13} \Delta t & 0 & 0 & 0 & \lambda_{17} \Delta t \\ \mu_{13} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{13} & 0 & 0 & 0 & 0 \\ \mu_{14} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{14} & 0 & 0 & 0 \\ \mu_{15} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{15} & 0 & 0 \\ \mu_{16} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{16} & 0 \\ \mu_{17} \Delta t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{17} \end{bmatrix}$$

Again, the following is the weight matrix between hidden layer and output layer

$$V = \begin{bmatrix} w_{11} & w_{21} & w_{31} & w_{41} & w_{51} & w_{61} & w_{71} & w_{81} & w_{91} & w_{(10)(1)} & w_{(11)(1)} & w_{(12)(1)} & w_{(13)(1)} & w_{(14)(1)} & w_{(15)(1)} & w_{(16)(1)} & w_{(17)(1)} \\ w_{12} & w_{22} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{23} & w_{33} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{24} & 0 & w_{44} & w_{54} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ w_{15} & 0 & 0 & 0 & w_{55} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{56} & w_{66} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ w_{17} & 0 & 0 & 0 & 0 & 0 & w_{77} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{78} & w_{88} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ w_{19} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{99} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_{7(10)} & 0 & w_{9(10)} & w_{(10)(10)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{9(11)} & 0 & w_{(11)(11)} & 0 & 0 & 0 & 0 & 0 & 0 \\ w_{1(12)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{(12)(12)} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{(12)(13)} & w_{(13)(13)} & 0 & 0 & 0 & 0 \\ w_{1(14)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{(14)(14)} & 0 & 0 & 0 \\ w_{1(15)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{(15)(15)} & 0 & 0 \\ w_{1(16)} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{(16)(16)} & 0 \\ w_{1(17)} & w_{1(12)} & 0 & 0 & w_{1(12)} & 0 & w_{1(12)} & 0 & w_{1(12)} & 0 & 0 & w_{(12)(17)} & 0 & 0 & 0 & 0 & w_{(17)(17)} \end{bmatrix}$$

Using eq. (1) - (17) and weight matrices W,V, authors established the following output equations:

$$Y_1 = w_{11}X_1 + w_{21}X_2 + w_{31}X_3 + w_{41}X_4 + w_{51}X_5 + w_{61}X_6 + w_{71}X_7 + w_{81}X_8 + w_{91}X_9 + w_{10(1)}X_{10} + w_{11(1)}X_{11} + w_{12(1)}X_{12} + w_{13(1)}X_{13} + w_{14(1)}X_{14} + w_{15(1)}X_{15} + w_{16(1)}X_{16} + w_{17(1)}X_{17} \tag{20}$$

$$Y_2 = w_{22}X_2 + w_{12}X_1 \tag{21}$$

$$Y_3 = w_{33}X_3 + w_{23}X_2 \tag{22}$$

$$Y_4 = w_{44}X_4 + w_{54}X_5 + w_{24}X_2 \tag{23}$$

$$Y_5 = w_{55}X_5 + w_{15}X_1 \tag{24}$$

$$Y_6 = w_{66}X_6 + w_{56}X_6 \tag{25}$$

$$Y_7 = w_{77}X_7 + w_{17}X_1 \tag{26}$$

$$Y_8 = w_{88}X_8 + w_{78}X_7 \tag{27}$$

$$Y_9 = w_{99}X_9 + w_{19}X_1 \tag{28}$$

$$Y_{10} = w_{(10)(10)}X_{10} + w_{7(10)}X_7 + w_{9(10)}X_9 \tag{29}$$

$$Y_{11} = w_{(11)(11)}X_{11} + w_{9(11)}X_9 \tag{30}$$

$$Y_{12} = w_{(12)(12)}X_{12} + w_{1(12)}X_1 \tag{31}$$

$$Y_{13} = w_{(13)(13)}X_{13} + w_{(12)(13)}X_{12} \tag{32}$$

$$Y_{14} = w_{(14)(14)}X_{14} + w_{1(14)}X_1 \tag{33}$$

$$Y_{15} = w_{(15)(15)}X_{15} + w_{1(15)}X_1 \tag{34}$$

$$Y_{16} = w_{(16)(16)}X_{16} + w_{1(11)}X_1 \tag{35}$$

$$Y_{17} = w_{(17)(17)}X_{17} + w_{1(17)}X_1 + w_{2(17)}X_2 + w_{5(17)}X_5 + w_{7(17)}X_7 + w_{9(17)}X_9 + w_{(12)(17)}X_{12} \tag{36}$$

Normally operable and failure Transition states are termed as up and down states, respectively. The distinct combinations of up and down state probabilities of various system states from (20) - (36) given as:

$$\begin{aligned}
 P_{up} &= Y_1 + Y_2 + Y_5 + Y_7 + Y_9 + Y_{12} \\
 &= w_{11}X_1 + w_{21}X_2 + w_{31}X_3 + w_{41}X_4 + w_{51}X_5 + w_{61}X_6 + w_{71}X_7 + w_{81}X_8 + w_{91}X_9 \\
 &\quad + w_{10(1)}X_{10} + w_{11(1)}X_{11} + w_{12(1)}X_{12} + w_{13(1)}X_{13} + w_{14(1)}X_{14} \\
 &\quad + w_{15(1)}X_{15} + w_{16(1)}X_{16} + w_{17(1)}X_{17} + (w_{12}X_1 + w_{22}X_2) \\
 &\quad + (w_{15}X_1 + w_{55}X_5) + (w_{17}X_1 + w_{77}X_7) + (w_{19}X_1 + w_{99}X_9) \\
 &\quad + (w_{(12)(12)}X_{12} + )w_{1(12)}X_1
 \end{aligned} \tag{37}$$

$$P_{down}(t) = 1 - P_{up}(t) \tag{38}$$

Now, the following equations yield the formulations for system reliability and profit function.:

$$Reliability = Y_1 + Y_2 + Y_5 + Y_7 + Y_9 + Y_{12} \tag{39}$$

$$G(t) = C_1 \times P_{up}(t) - C_2 \times t - C_3 \tag{40}$$

Where  $C_1$ : Revenue cost,  $C_2$ : Repair cost per unit time,  $C_3$ : Establishment cost,  $P_{up}(t)$ : Probability of operable states

### 6.1. Reliability Based Sensitivity Analysis

The reliability based sensitivities w.r.t. failure parameters  $(\lambda_2), (\lambda_5), (\lambda_7), (\lambda_8), (\lambda_{14})$  and environmental failure  $(\lambda_{17})$  are evaluated as follows:

$$\frac{\partial P_{up}}{\partial \lambda_2} = -\Delta t P_5(t) \tag{41}$$

$$\frac{\partial P_{up}}{\partial \lambda_5} = -\Delta t P_2(t) - \Delta t P_5(t) \tag{42}$$

$$\frac{\partial P_{up}}{\partial \lambda_7} = -\Delta t P_9(t) \tag{43}$$

$$\frac{\partial P_{up}}{\partial \lambda_8} = -\Delta t P_7(t) - \Delta t P_9(t) \tag{44}$$

$$\frac{\partial P_{up}}{\partial \lambda_{14}} = -\Delta t P_1(t) \tag{44}$$

$$\frac{\partial P_{up}}{\partial \lambda_{17}} = -\Delta t [ P_1(t) + P_2(t) + P_5(t) + P_7(t) + P_9(t) + P_{12}(t) ] \tag{45}$$

### 6.2. Numerical Example

To analyze the results of a complex /repairable system, authors assumed the following data:

$$\begin{aligned} \mu_i = 1, \quad \text{where } i = 1,2,3 \dots 10; \quad \lambda_2 = 0.01, \quad \lambda_3 = 0.01, \quad \lambda_4 = 0.02, \lambda_5 = 0.02, \quad \lambda_6 = 0.015, \\ \lambda_7 = 0.02, \lambda_8 = 0.02, \quad \lambda_9 = 0.02, \quad \lambda_{10} = 0.02, \lambda_{11} = 0.02, \quad \lambda_{12} = 0.01, \lambda_{13} = 0.01, \\ \lambda_{14} = 0.01, \lambda_{15} = 0.01, \quad \lambda_{16} = 0.01, \lambda_{17} = 0.01 \end{aligned}$$

Eq. (39) provides the reliability of the system using BPNN approach and their values are represented in Table 1 and graphically shown in Fig. 8 and Fig. 9.

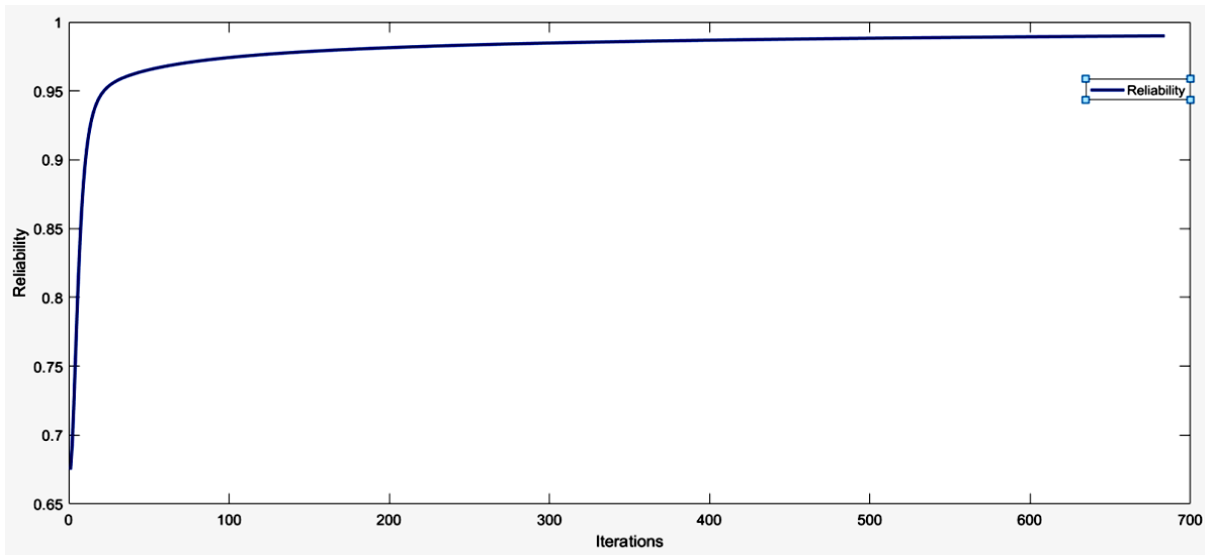


Figure 8. Reliability V/s Iteration

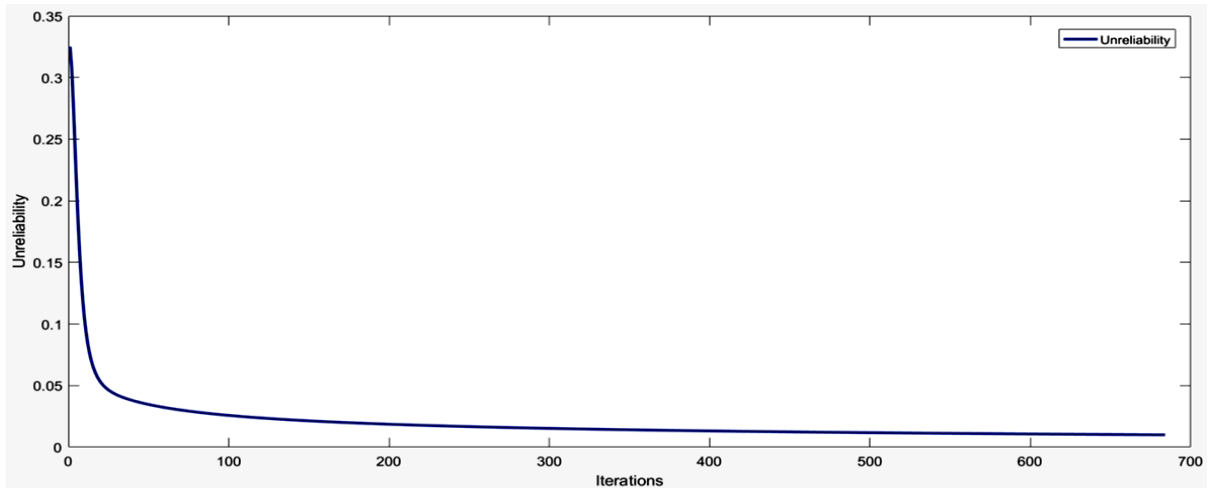


Figure 9. Reliability V/s Iteration

Table 1. Reliability V/S Iteration

|               |        |        |        |        |        |        |        |
|---------------|--------|--------|--------|--------|--------|--------|--------|
| Iterations    | 1      | 25     | 50     | 100    | 150    | 200    | 250    |
| Reliability   | 0.6748 | 0.9583 | 0.9654 | 0.9742 | 0.9786 | 0.9814 | 0.9833 |
| Unreliability | 0.3252 | 0.0417 | 0.0346 | 0.0258 | 0.0214 | 0.0186 | 0.0167 |
| Iterations    | 300    | 350    | 400    | 450    | 500    | 600    | 684    |
| Reliability   | 0.9848 | 0.9859 | 0.9868 | 0.9876 | 0.9882 | 0.9893 | 0.99   |
| Unreliability | 0.0152 | 0.0141 | 0.0132 | 0.0124 | 0.0118 | 0.0107 | 0.01   |

The values of profit function can be obtained by (40). On considering the establishment cost  $C_3=1$ , revenue cost  $C_1=0.8$  units and several repair costs  $C_2 = 0.2, 0.3, 0.4, 0.6$  units respectively, for analysis and comparison of the profit function. The graphics in Figure 10 and Table 2 are representing Profit function values, evaluated from (40).

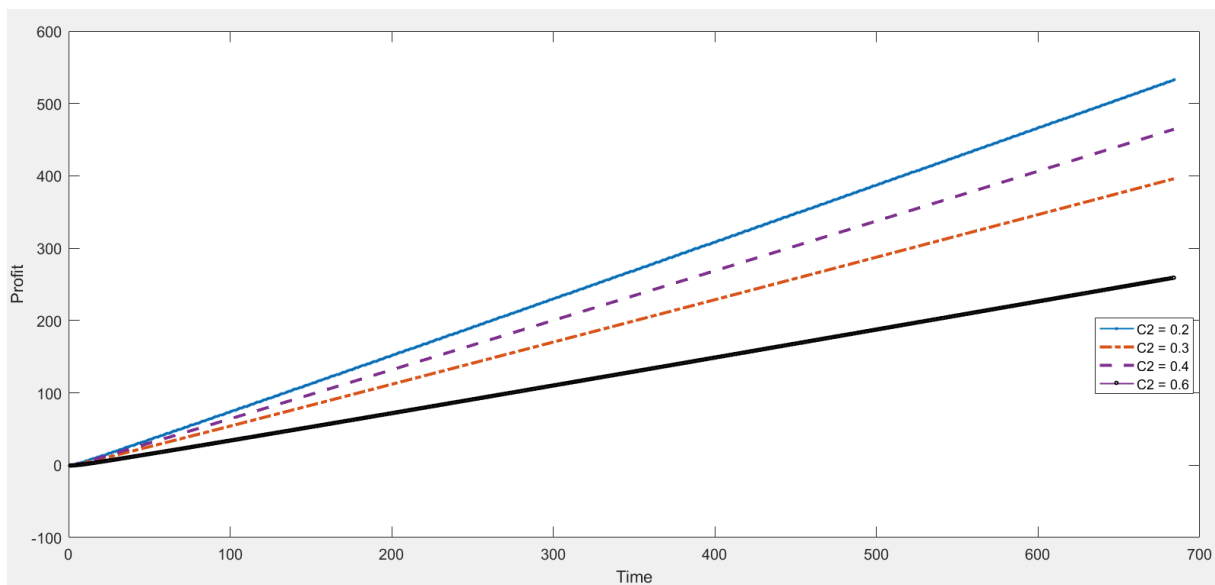


Figure 10. Comparative Profit V/s Time

**Table 2.** Profit Function Value for Distinct Repair Cost Vs Time/ Epochs

| Loopings /Time | Profit Function Value (Units) |                     |                     |                     |
|----------------|-------------------------------|---------------------|---------------------|---------------------|
|                | C <sub>2</sub> =0.2           | C <sub>2</sub> =0.4 | C <sub>2</sub> =0.6 | C <sub>2</sub> =0.8 |
| 1              | -0.660095                     | -0.860095           | -1.060095           | -1.260095           |
| 50             | 25.818374                     | 15.818374           | 5.818374            | -4.181626           |
| 100            | 54.639366                     | 34.639366           | 14.639366           | -5.360634           |
| 150            | 83.706661                     | 53.706661           | 23.706661           | -6.293339           |
| 200            | 112.912243                    | 72.912243           | 32.912243           | -7.087757           |
| 250            | 142.209553                    | 92.209553           | 42.209553           | -7.790447           |
| 300            | 171.573405                    | 111.573405          | 51.573405           | -8.426595           |
| 350            | 200.988346                    | 130.988346          | 60.988346           | -9.011654           |
| 400            | 230.444091                    | 150.444091          | 70.444091           | -9.555909           |
| 450            | 259.933386                    | 169.933386          | 79.933386           | -10.066614          |
| 500            | 289.450889                    | 189.450889          | 89.450889           | -10.549111          |
| 550            | 318.992534                    | 208.992534          | 98.992534           | -11.007466          |
| 600            | 348.555142                    | 228.555142          | 108.555142          | -11.444858          |
| 650            | 378.136169                    | 248.136169          | 118.136169          | -11.863831          |
| 684            | 398.260718                    | 261.460718          | 124.660718          | -12.139282          |

**Table 3.** Current Market Price of Components Used in Standalone Smart Irrigation System

| Component                       | Unit Cost (INR) | Quantity | Total cost(INR) |
|---------------------------------|-----------------|----------|-----------------|
| Soil Moisture Sensor            | 3500.00         | 1        | 3500.00         |
| Arduino                         | 1000.00         | 1        | 1000.00         |
| Raspberrypi                     | 5994.00         | 1        | 5994.00         |
| Modem                           | 599.00          | 1        | 599.00          |
| Capacitive Display              | 3100.00         | 1        | 3100.00         |
| 3-Way Solenoid Valve            | 3200.00         | 1        | 3200.00         |
| Wireless Network Device         | 1400.00         | 1        | 1400.00         |
| Photovoltaic panel (per KW)     | 28000.00        | 3        | 84000.00        |
| Battery                         | 10500.00        | 4        | 42000.00        |
| Charge control unit (mppt+Inv.) | 28000.00        | 1        | 28000.00        |
| Pump                            | 12000.00        | 1        | 12000.00        |
| Tank                            | 4000.00         | 1        | 8000.00         |

**6.3. Cost Analysis**

To control the system in a smart irrigation system, very expensive devices are employed. However, in this case, we employ relatively low-cost hardwires that an Indian farmer can simply purchase and install in farm. A smart watering system with fewer sensors is also more cost effective [13]. Observing the current market prices given above in Table 3, the total cost of hardware is around Rs.180000. This is a fair initial investment for a small single-unit arrangement,

and the cost can be recovered by reducing waste water and electricity costs (in comparison of traditional methods).

**6.4. Sensitivity Analysis**

To analyze the system sensitivity with respect to failures, the authors have analyzed table 4, table 5 that derived from (41)-(45) and represented graphically in Fig. 11.

Table 4. Sensitivity V/S Time

| $\Delta t$ | $\frac{\partial P_{up}}{\partial \lambda_2}$ | $\frac{\partial P_{up}}{\partial \lambda_5}$ | $\frac{\partial P_{up}}{\partial \lambda_7}$ | $\frac{\partial P_{up}}{\partial \lambda_8}$ | $\frac{\partial P_{up}}{\partial \lambda_{14}}$ | $\frac{\partial P_{up}}{\partial \lambda_{17}}$ |
|------------|--|--|--|--|---|---|
| 0.01       | 0  | 0  | 0  | 0.0000E+00                                   | -0.01   | -0.01   |
| 0.02       | 0  | 0  | 0  | 0.0000E+00                                   | -0.02   | -0.02   |
| 0.03       | 0  | 0  | 0  | 0.0000E+00                                   | -0.03   | -0.03   |
| 0.04       | 0  | 0  | 0  | 0.0000E+00                                   | -0.04   | -0.04   |
| 0.05       | 0  | 0  | 0  | 0.0000E+00                                   | -0.05   | -0.05   |
| 0.06       | 0  | 0  | 0  | 0.0000E+00                                   | -0.06   | -0.06   |
| 0.07       | 0  | 0  | 0  | 0.0000E+00                                   | -0.07   | -0.07   |
| 0.08       | 0  | 0  | 0  | 0.0000E+00                                   | -0.08   | -0.08   |
| 0.09       | 0  | 0  | 0  | 0.0000E+00                                   | -0.09   | -0.09   |
| 0.1        | 0  | 0  | 0  | 0.0000E+00                                   | -0.1  | -0.1  |
| 0.11       | 0  | 0  | 0  | 0.0000E+00                                   | -0.11   | -0.11   |
| 0.12       | 0  | 0  | 0  | 0.0000E+00                                   | -0.12   | -0.12   |
| 0.13       | 0  | 0  | 0  | 0.0000E+00                                   | -0.13   | -0.13   |
| 0.14       | 0  | 0  | 0  | 0.0000E+00                                   | -0.14   | -0.14   |
| 0.15       | 0  | 0  | 0  | 0.0000E+00                                   | -0.15   | -0.15   |
| 0.16       | 0  | 0  | 0  | 0.0000E+00                                   | -0.16   | -0.16   |
| 0.17       | 0  | 0  | 0  | 0.0000E+00                                   | -0.17   | -0.17   |
| 0.18       | 0  | 0  | 0  | 0.0000E+00                                   | -0.18   | -0.18   |
| 0.19       | 0  | 0  | 0  | 0.0000E+00                                   | -0.19   | -0.19   |
| 0.2        | 0  | 0  | 0  | 0.0000E+00                                   | -0.2  | -0.2  |

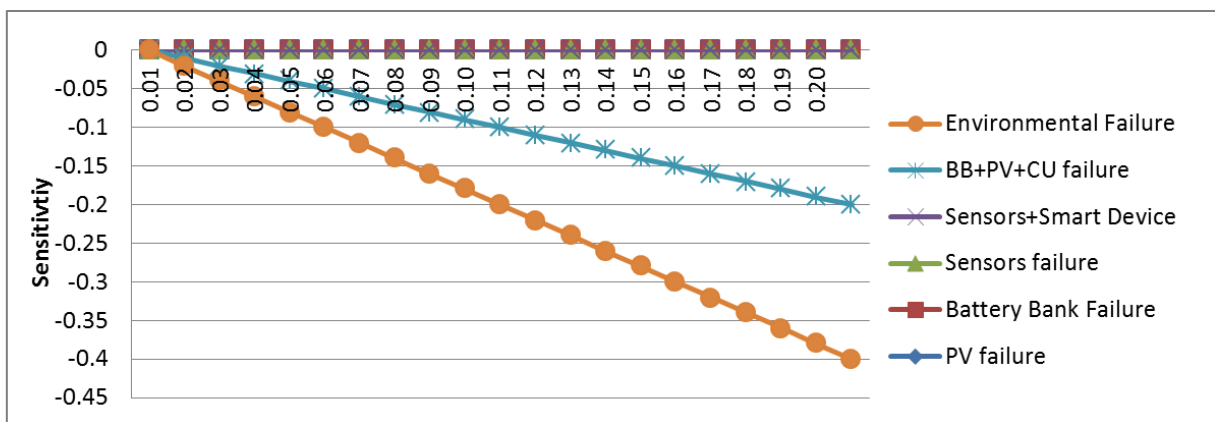


Figure 11. Sensitivity V/s Time, (initially)

Table 5. Sensitivity V/S Time

| $\Delta t$ | $\frac{\partial P_{up}}{\partial \lambda_2}$ | $\frac{\partial P_{up}}{\partial \lambda_5}$ | $\frac{\partial P_{up}}{\partial \lambda_7}$ | $\frac{\partial P_{up}}{\partial \lambda_8}$ | $\frac{\partial P_{up}}{\partial \lambda_{14}}$ | $\frac{\partial P_{up}}{\partial \lambda_{17}}$ | $\Delta t$ |
|------------|--|--|--|--|---|---|------------|
| 0.01       | -0.00000054                                  | -0.00000108                                  | -0.00000054                                  | -1.0800E-06                                  | -0.00000081                                     | -0.00000351                                     | 0.01       |
| 0.02       | -0.00000108                                  | -0.00000216                                  | -0.00000108                                  | -2.1600E-06                                  | -0.00000162                                     | -0.00000702                                     | 0.02       |
| 0.03       | -0.00000162                                  | -0.00000324                                  | -0.00000162                                  | -3.2400E-06                                  | -0.00000243                                     | -0.00001053                                     | 0.03       |
| 0.04       | -0.00000216                                  | -0.00000432                                  | -0.00000216                                  | -4.3200E-06                                  | -0.00000324                                     | -0.00001404                                     | 0.04       |
| 0.05       | -0.0000027                                   | -0.0000054                                   | -0.0000027                                   | -5.4000E-06                                  | -0.00000405                                     | -0.00001755                                     | 0.05       |
| 0.06       | -0.00000324                                  | -0.00000648                                  | -0.00000324                                  | -6.4800E-06                                  | -0.00000486                                     | -0.00002106                                     | 0.06       |
| 0.07       | -0.00000378                                  | -0.00000756                                  | -0.00000378                                  | -7.5600E-06                                  | -0.00000567                                     | -0.00002457                                     | 0.07       |
| 0.08       | -0.00000432                                  | -0.00000864                                  | -0.00000432                                  | -8.6400E-06                                  | -0.00000648                                     | -0.00002808                                     | 0.08       |
| 0.09       | -0.00000486                                  | -0.00000972                                  | -0.00000486                                  | -9.7200E-06                                  | -0.00000729                                     | -0.00003159                                     | 0.09       |
| 0.1        | -0.0000054                                   | -0.0000108                                   | -0.0000054                                   | -1.0800E-05                                  | -0.0000081                                      | -0.0000351                                      | 0.1        |
| 0.11       | -0.00000594                                  | -0.00001188                                  | -0.00000594                                  | -1.1880E-05                                  | -0.00000891                                     | -0.00003861                                     | 0.11       |
| 0.12       | -0.00000648                                  | -0.00001296                                  | -0.00000648                                  | -1.2960E-05                                  | -0.00000972                                     | -0.00004212                                     | 0.12       |
| 0.13       | -0.00000702                                  | -0.00001404                                  | -0.00000702                                  | -1.4040E-05                                  | -0.00001053                                     | -0.00004563                                     | 0.13       |
| 0.14       | -0.00000756                                  | -0.00001512                                  | -0.00000756                                  | -1.5120E-05                                  | -0.00001134                                     | -0.00004914                                     | 0.14       |
| 0.15       | -0.0000081                                   | -0.0000162                                   | -0.0000081                                   | -1.6200E-05                                  | -0.00001215                                     | -0.00005265                                     | 0.15       |
| 0.16       | -0.00000864                                  | -0.00001728                                  | -0.00000864                                  | -1.7280E-05                                  | -0.00001296                                     | -0.00005616                                     | 0.16       |
| 0.17       | -0.00000918                                  | -0.00001836                                  | -0.00000918                                  | -1.8360E-05                                  | -0.00001377                                     | -0.00005967                                     | 0.17       |
| 0.18       | -0.00000972                                  | -0.00001944                                  | -0.00000972                                  | -1.9440E-05                                  | -0.00001458                                     | -0.00006318                                     | 0.18       |
| 0.19       | -0.00001026                                  | -0.00002052                                  | -0.00001026                                  | -2.0520E-05                                  | -0.00001539                                     | -0.00006669                                     | 0.19       |
| 0.2        | -0.0000108                                   | -0.0000216                                   | -0.0000108                                   | -2.1600E-05                                  | -0.0000162                                      | -0.0000702                                      | 0.2        |

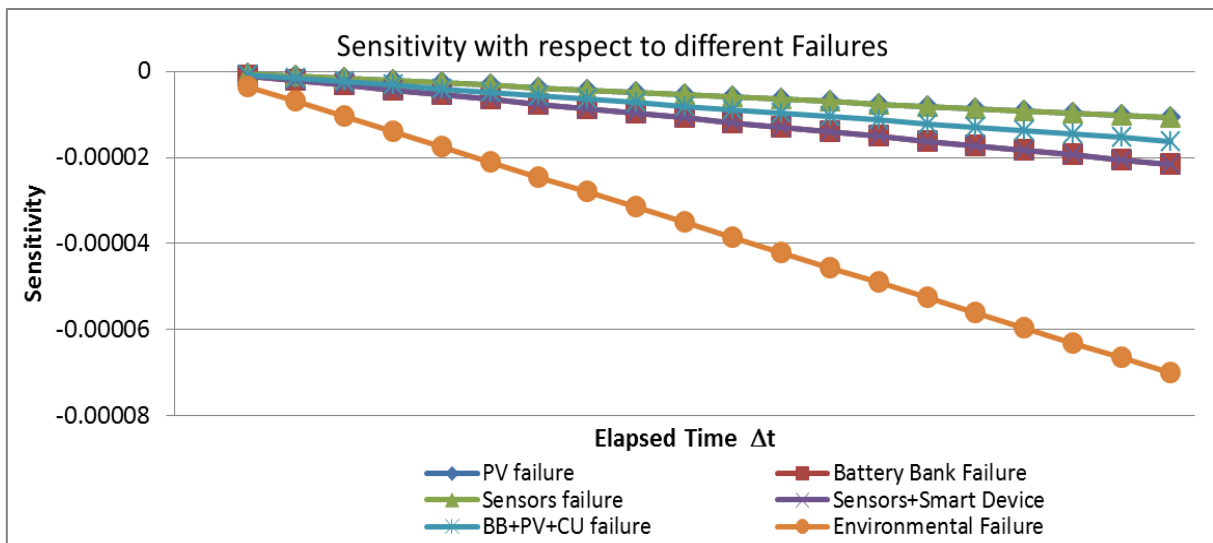


Figure 12. Sensitivity V/s Time

## 7. Discussion & Conclusions

The results of the standalone smart irrigation system in this paper have shown the effective management of irrigation water resources, electric power generation systems, and superintending the various irrigation statistics like soil moisture, environmental humidity, and temperature.

The management of these statistics enables a controlled irrigation process and enhances the yield. The system's initial reliability is 0.6748, as indicated in Table 1. After increasing the number of iterations/epochs, the weights of synapses employed as failures/repairs are updated using the gradient descent method of BPNN. The system's reliability approaches 0.9900 after the 684th iteration (tolerance range of 10<sup>-4</sup>), which is much closer to the value of 1.0000. In the same table, the value of unreliability can be observed. The relevance of the BPNN technique is graphically depicted in Fig.8 and Fig.9 as the reliability of a sophisticated smart irrigation system rises with each iteration.

The profit function progressively grows with regard to iterations, as seen by the outcomes of (40), as shown in Table 2. Fig. 10 additionally demonstrates the overall comparability of profits versus various repair expenses. According to Table 2, the profit function reaches its maximum each time/looping when the repair cost is lower, i.e. 0.2 units, which might help system administrators make better decisions. Table 3 exhibits the system's sensitivity to failures in relation to PV ( $\lambda_2$ ), BB ( $\lambda_5$ ), Sensors ( $\lambda_7$ ), Sensors+Smart device ( $\lambda_8$ ), PV+BB+CU ( $\lambda_{14}$ ) and environmental failure ( $\lambda_{17}$ ). The pattern of sensitivity shows that initially (when  $t = 0$ ) system is sensitive to environment failure but after time  $t$ , the system becomes sensitive to power module as well as environment failure (see Fig.11, Fig.12) and it is apparent that standalone smart irrigation systems seem to be more vulnerable to environmental failure. This highlights the contribution of the operating environment to the intended standalone smart irrigation system.

The results showed that self powered irrigation systems have a great impact and are quite feasible considering the availability of natural resources in India. Online monitoring by an IoT mobile application increases crop growth by effective management of land moisture, humidity, and temperature. This helps the farmer achieve optimal use and calculates the volume of required water for irrigation. The only thing required is the successful performance of each and every subsystem and component to make this smart system more reliable. Though the initial establishment cost increases as the quality components are included in the study/practice, this can be compensated for by the quality of the crop and increment in yield. Also, if a system operates with high reliability, then it decreases the repair cost, which is another factor in saving money. For the encouragement of farmers to use smart irrigation systems, the initial investment cost could be subsidized by

the government in favor of the environment.

## Acknowledgements

The author is grateful for the contributions of associate fellows, experts and affiliate institutes, for providing supports in all required forms, in preparing this manuscript.

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