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Accurate And Efficient Power Generation Of Photovotaic Systems Using Wireless Technology

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Abstract— **In this work, automation and efficient power generation of a solar park are studied to overcome high inefficiencies that exist in most of the present parks. The inefficiencies arise from many reasons such as stationary condition of the photovoltaic panels to name one. The other problems arise because such parks extend over large areas and maintenance of efficient power generation becomes difficult if all of the panels are mounted such that they track the Sun for maximum power generation.**

In this work, the entire plant is operated from a single control room and all the tracking machines are commanded to follow the Sun from the control room through wireless signals. The entire motion of the panels is controlled from this room using Arduino Mega microcontroller. In addition, to enhance the accuracy and reliability, several additional measures have been incorporated so that through an accurate feedback system or fault detection mechanism has been provided for in this work.

Index Terms— **Renewable energy, Solar energy, Wireless control, Torque minimization, Accurate tracking of the Sun.**

I. INTRODUCTION

Fossil fuels namely, crude oil, natural gas, and coal are the primary fuels in use these days. These are used in industrial processes, heating of homes, etc. The downside of use of such fuels is that they cause heavy air pollution which causes diseases. It leads to human suffering due to such diseases, and also it increases healthcare costs. The fact of the matter is that the economy in fuel consumption is measured without considering its effect on healthcare costs. If the healthcare costs are also included then the fuel consumption costs will be much higher [1].

The renewable energy forms are solar, hydro, biomass, and wind. The hydro power generation has required large human resettlements which have become quite difficult in those countries which have high population density. The wind energy requires higher wind velocity for economical power generation. It is not suitable over a large mass of land areas. On the other hand, solar energy is quite widespread all over the world. The price of photovoltaic panels has come down very rapidly in the last five years. In most of the countries, one can generate power at the rate of $ 0.12 per kilowatt hour . On the other hand, the cost of power generation using oil is not much cheaper than that of the solar.

The oil fired boilers give rise to emission problems. It affects large areas around the power generation plant. For example, in the purification of seawater, the thermal energy input used to be from oil. But the negative aspect of this was that the areas around such thermal plants had high air pollution.

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A. SOLAR POWER ELECTRICITY GENERATION

in this form of electricity generation, a photovoltaic panel is used. Such panels convert incident Sun's rays into electricity which has a power conversion efficiency of about 15% or at the most 20% of the incident solar energy. The incident energy should be perpendicular to the surface of the photovoltaic panels. In most parts of the world, photovoltaic panels are fixed to the ground, facing south in the northern hemisphere, and they are tilted at an angle equal to the latitude of the place of use. In such fixed panels, the Sun's rays are seldom perpendicular to the panels. Therefore, energy conversion becomes less, equal to 33% of the incident energy during a year [2]. This fact has not been realized in most of the applications where solar energy is being used to generate electricity. The panels are very expensive. Therefore, a vast amount of capital is not properly utilized and not very well understood.

These panels extend over large areas as shown in Fig. 1. The energy content of the Sun's rays is much less as compared to the fossil fuel energy content per unit volume. Therefore, to generate an equal amount of electricity using solar energy, it requires large land areas. Normally, these panels generate electricity in a very distributed fashion (spreadout over a large land area). Therefore, the maintenance or power generation requires large human involvement for a power plant (solar) as compared to the thermal and hydro power plants. In other words, per kilowatt hour of energy generation, it may require more land area in case of solar power. In this way, we can say that both solar and hydro power require large land areas for a given amount of power generation.

Solar energy generated electricity is maximum in summer whereas the hydro power is minimum due to water scarcity or lower levels of water in the dams. In addition, solar energy generated electricity is greater in the desert areas where land is not fertile whereas mostly in the hydro power areas the land is expensive. In general, in tropical countries, the electricity shortage is in summer when solar energy gives the best output.

Due to the spreadout setup in solar power generation, efficient maintenance and power generation would be a tedious task i.e., to look after each of the panels if it is fixed or even tracking the way it is being done presently.

The purpose of the present work is to carry out the power generation in the most economical and efficient way. This is done first by tracking and also by introducing wireless controlled automation along with the fault detection automatic feedback.

Just for information, one obtains 33 percent more power if tracking is adopted in place of fixed panel power generation

[2]. The design of such solar tracking systems is a bit complex in nature, but its benefits far outweigh the stationary arrangement.

The tracking can be done using two axes or single axis . The dual-axis tracking requires that two angles be simultaneously adjusted whereas, in the single axis, the tracking is done by varying one angle only at a given time. However, there is a need to adjust another angle called the seasonal variation angle also. This seasonal variation angle is extremely slow changing. In fact, if one changes this angle by an amount as low as 1° per day then also one can achieve almost the peak efficiency of energy conversion.

This variation of angles arises from the motion of the Earth around the Sun which is called the orbital motion. While the Earth moves around the Sun, it spins about its own axis and this is called the tracking axis. The orientation of the Earth's axis with respect to the Sun changes extremely slowly when viewed from the Sun's ecliptic plane. This is called the seasonal variation.

Hence, it is quite clear that one has to generate electricity using solar energy by adopting the tracking process. Normally, this tracking is done where one finds the optimal position or optimal orientation by using photosensors. These sensors search for the brightest part in the sky with the assumption that the brightest spot leads to the maximum conversion of solar energy. If we have large territory over which solar panels are spread out, then the optimal orientations would vary from a set of panels to another. Here we are assuming, as is done commonly in practice, that a number of panels are mounted on one structure. Therefore, there is a large number of structures in a given solar park. Each structure has its own photosensor. Therefore, when scattered cloudy conditions are present, then there is nothing in common between each of the structures. If a fault arises in a given structure as far as the optimal orientation is concerned, one has to maintain such optimal conditions, structure by structure.
Therefore, large manpower is required for optimal power generation in such arrangments.

Figure 2A shows another way of mounting solar panels where the tracking axis is controlled using a stepper motor whose rotation rate is precise. In this arrangement, the command for tracking is sent from the central control room to the various stepper motors on the tracking machines. This is possible because the Sun's rays are incident on all the solar panels in a parallel fashion. Therefore, the orientations of the Sun from each structure will be one specific angle at a given instant of time. In other words, one global command is sufficient to orient all of the structures at a given instant of time which is not possible if photosensors are used on each of the sturctures. In addition to this, one can change the seasonal variation angle at midnight for example, requiring no further change for the next 24 hours because of the fact that the declination changes by 23 degrees aproximately in 3 months [3].

This simplifies the power generation process because all such machines can be commanded from one centralized location from sunrise to sunset. These panels are programmed from the control room to return to the morning position or morning orientation. After the sunset, it is returned at a much faster rate than that with the daylight tracking. After returning, they are reoriented for the daily motion and are held in the starting position for the night. Since the Earth's spin rate is uniform, the stepper motor has to rotate at the constant but extremely slow rate as does the Earth.

B. SOLAR POWER ADOPTION

Until recently, solar energy systems were only accessible to the wealthy due to their high cost. However, due to sharply declining costs, universal access to solar paneling systems has become a reality. In the early 2000s, the average U.S. solar system cost was $10 per Watt; in 2013, the price per Watt was just below $4. As a result, the number of photovoltaic systems installed in the U.S. has drastically increased among residential and commercial spaces [1]. Solar energy in recent times is being used very extensively [4-8]. Some papers on tracking can be seen in [9-13].

II. WIRELESS CONTROL OF THE SOLAR POWER PLANT

So far, the efficiency in solar power generation was not given too much importance. The reason was that the subtle nature of the energy content of the Sun's rays which depend on the direction of the rays. If the rays of the Sun are incident normal to the surface of the photovoltaic panels, then the conversion will be maximum. Any incidence of these rays in an oblique manner will give rise to lesser energy conversion. In most of the time, starting from early morning to the sunset, the rays are oblique to the receiving surfaces, thereby, converting less than possible maximum energy. This problem has been taken care of by a solar tracking process where the normal to the receiving surface matches with the Sun's direction all the time. This matching is done by an iterative process where optical sensors are used to match with the direction which yields the maximum intensity of the Sun's rays. The designer of such instruments does not consider the Earth's motion around the Sun to locate exactly the Sun's direction. Here, the designer relies on the optical sensor by finding the maximum direction of the intensity of light which need not be Sun's direction when scattered cloudy conditions encountered [3, 14].

Considering above, we are addressing further issues which arise in improving the efficiency and reliability of the power generation process. The points addressed in this work are:

1. The inclusion of an encoder with the daily tracking stepper motor which ensures the movement of the motor. If there is no motion, then the system is assumed to have failed. The motion of the motor shaft is the deciding factor.

2. Two limit switches are also included to determine the span of the rotation of the panels. This gives a positive assurance that the span is not exceeded. This gives further check on the actual motion of the panels rather than relying entirely on the software.

3. In this work, additional manual control is also incorporated in the Control Room. In case several machines develop problems, then all the machines in the plant can be provided correct positioning from one location at the Control Room rather than attending to several machines individually.

In reference [3], the authors generate electricity using solar tracking where the Earth's motion around the Sun is considered as well as in this work. In these works, wireless control is resorted to. In this work, the wireless motion control of the solar panels is carried out where the solar panels are mounted on different tracking machines as shown in Fig. 3 where there is a control room (1) from where three tracking machines (2, 3, 4) are controlled. These tracking machines have two motors within there (M1, M2). Both of these motors are stepper motors.

One of these (M1) is for daily tracking of the Sun, and the other one (M2) is for seasonal variation. This seasonal variation is done once a day at midnight. One of the tracking machines is shown in Fig. 2A. These machines have gearboxes as shown in Fig. 2B. These gearboxes are utilized for stepping down the speed of rotation of the solar panels. So the tracking process involves uniform motion of the tracking motor which is further reduced due to gearboxes. So the control process involves sending signals at certain frequencies to the tracking motor for its rotation where the solar panels rotate at the same rate as the earth does but in opposite direction of the spin of the Earth.

In this work, the forward motion, the reverse motion to come back to the morning position and waiting period in the morning position is controlled from the Control Room using programs written in Arduino Mega and Nano [15-17]. Here, the failure at the machines was wirelessly transmitted to the Control Room as well as LED bulbs were lit on the particular machine. This stoppage of the machine was looked at manually by an operator where manual adjustment of the position is also there. Here, there was information available at the Control Room as to which of the machines had failed.

A. EXPERIMENTAL DETAILS

In Fig. 4, we have Arduino Mega where signals are transmitted through a radio frequency transmitter. The signals are generated by writing code for the forward tracking motion between sunrise to sunset, then the return motion at four times the speed of the tracking motion. After the panel returns to the initial position, it waits for the next morning. This figure also shows a clock used for starting the motion in the morning. The forward motion is reversed using the clock at 6 P.M. This time of 6 P.M. is arrived at by counting the number of pulses.

In this work, the limit switches are included as shown in Fig. 5 where the limit switches are connected to the stepper motor driver. In addition, the encoder gives continuous feed-back through Arduino Uno shown in Fig. 8. In this figure, if the rotation stops, then the relay is activated to disconnect the power supply. After the power supply is stopped, then LED lights go on as shown in Figs. 6 and 7. In Fig. 6 the light is shown to the right of the Arduino Nano. This message is transmitted to the Main Control Center and another LED in the room is also lit as shown in Fig. 7. Here, the three lights correspond to three separate tracking machines. After seeing the light, an operator has to check the error and presses the reset button shown in Fig.
8.

In case of failure of large number of tracking machines, one has to check the faults at these machines and then manually correct the positioning of all the machines from the Control Room using Manual Controller shown in Fig. 4 at the left top corner. This control is achieved by having a potentiometer for both forward and return motions. The forward motion is given by turning the knob clockwise from the middle position. The reverse direction is achieved by turning the knob counter-clockwise from the middle position. The magnitude of the speed depends upon how far one has set the knob position away from the middle position. The second potentiometer is used for seasonal variation in a similar manner.

The tracking motion is generated at Arduino Mega in the Main Control Room and sent wirelessly to all the machines using a transmitter in the Main Room shown in Fig. 4. Similarly, the reverse direction motion is sent in this way.

The signals from the machines in case of failures are sent wirelessly from Arduino Uno at the machine level shown in Fig. 6 and received at the Main Control Room by a receiver shown in Fig. 7.

The declination correction is done by a separate motor with each of the tracking machines. This correction is done at midnight where a signal is sent from the Main Control Room to all the machines. The motion to any of the two motors is specified by an identification code sent from the main control room to the receiving station at the machine.

The Manual Control at the machine level is shown in Fig. 5 at the top right corner. Here, the potentiometers are used just like in the main control room for the direction of rotation or magnitude of the speed of each stepper motor. After making the correction, the system is set on auto mode.

Tables 1 to 5 specify the wire connections corresponding to their respective figures.

The experiments were carried out to test the tracking motion, reverse motion, and waiting period. The Figs. 9 and 10 show the experimental setup. It was found that the system was performing well.

III. CONCLUSION

In the present work, the automation of the solar power plant was discussed. It involves generating and sending signals from the main control room to various solar tracking machines. Each of these machines has two motors, one for the tracking motion, and the other for the seasonal angle variation. The signals were generated using Arduino Mega and transmitted wirelessly through a radio transmitter. This signal is received at the machine level by a receiver where these signals are interpreted by Arduino Nano and pulses are sent to the intended motor. If any fault happens at the machine level, then an Arduino Uno (a) lights an LED at the machine as well as (b) it sends a signal to the Main Control Room about the failure at the particular machine.

There is a provision of manually repositioning the solar panels after correcting for the faults. This can be also done globally from the Control Center. In addition, limit switches were provided for additional safety to take care of the angular span of the rotation of the panels.

Besides, at the machine level, encoders were incorporated at the stepper motors to ensure the continuous motion.

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FIG. 1 PHOTOVOLTAIC PANELS IN A SOLAR PARK

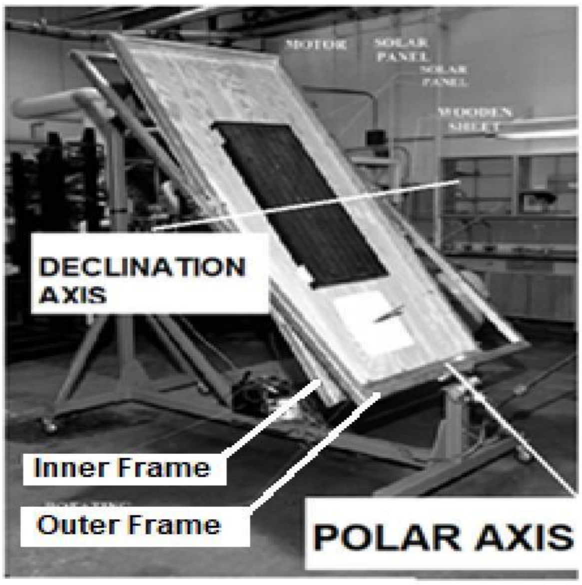

FIG. 2A TRACKING MACHINE

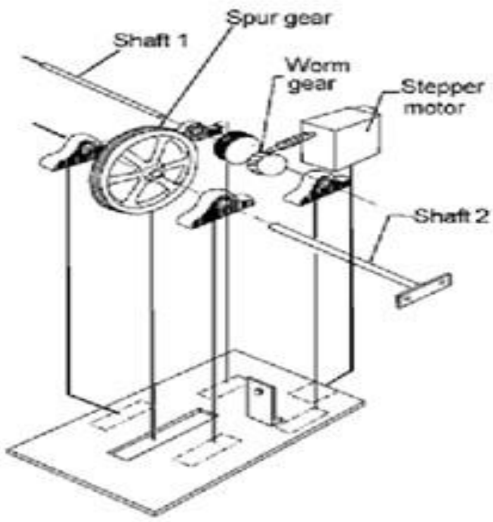

FIG. 2B GEAR REDUCTION

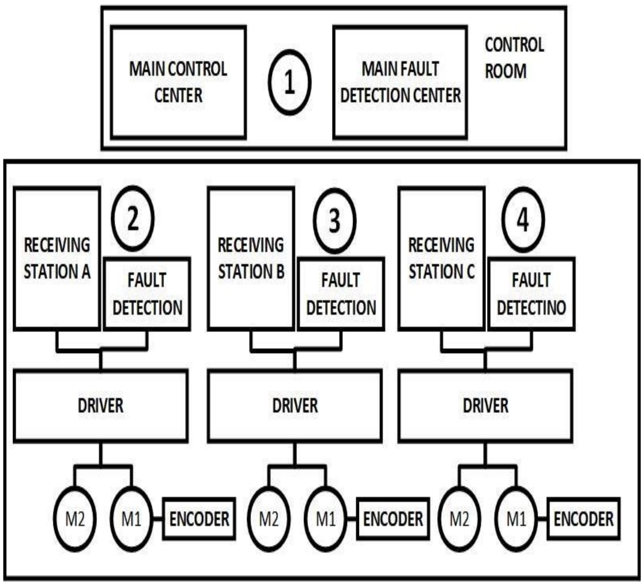

FIG. 3 PLANT LAYOUT

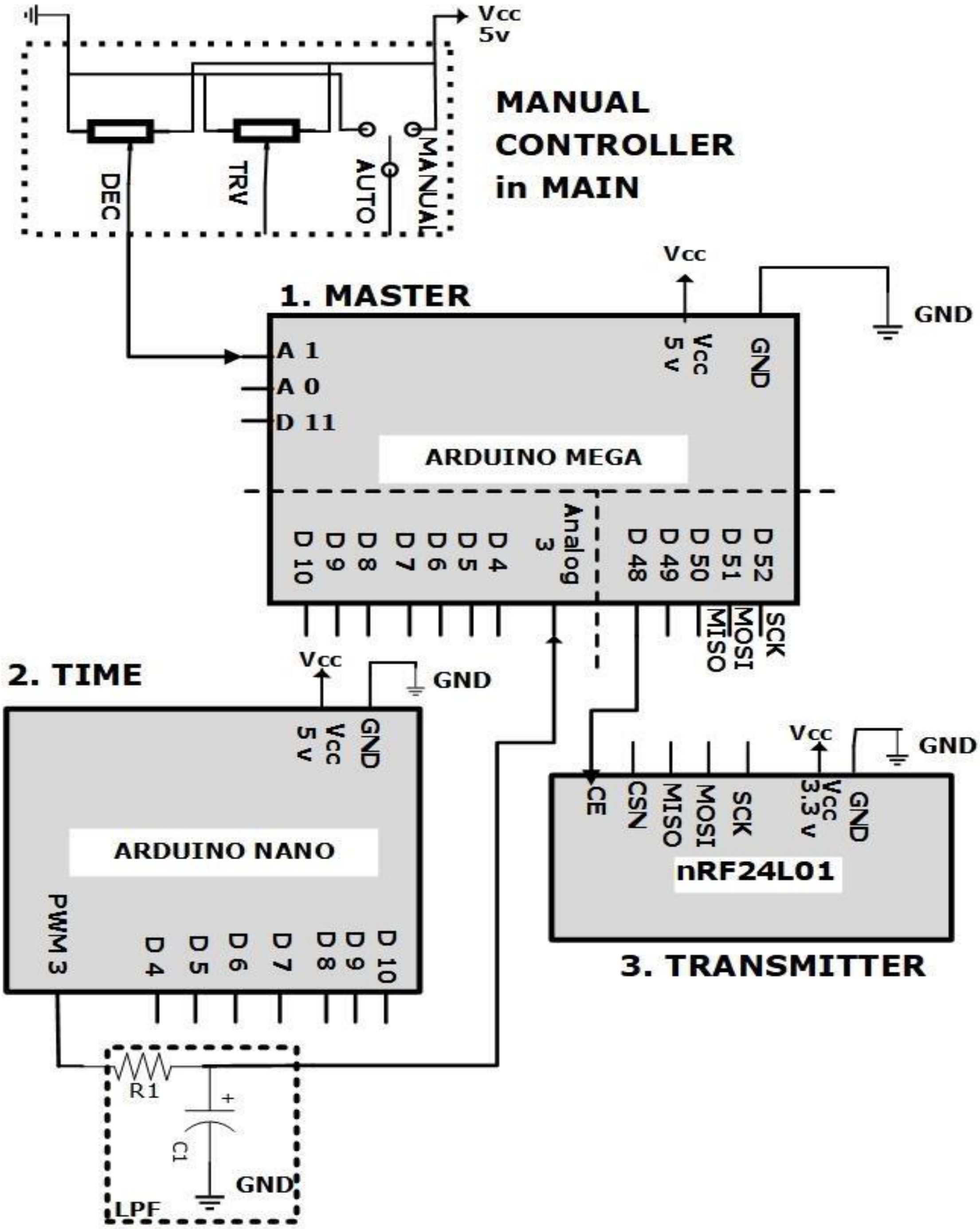

FIG. 4 - MASTER CONTROL UNIT

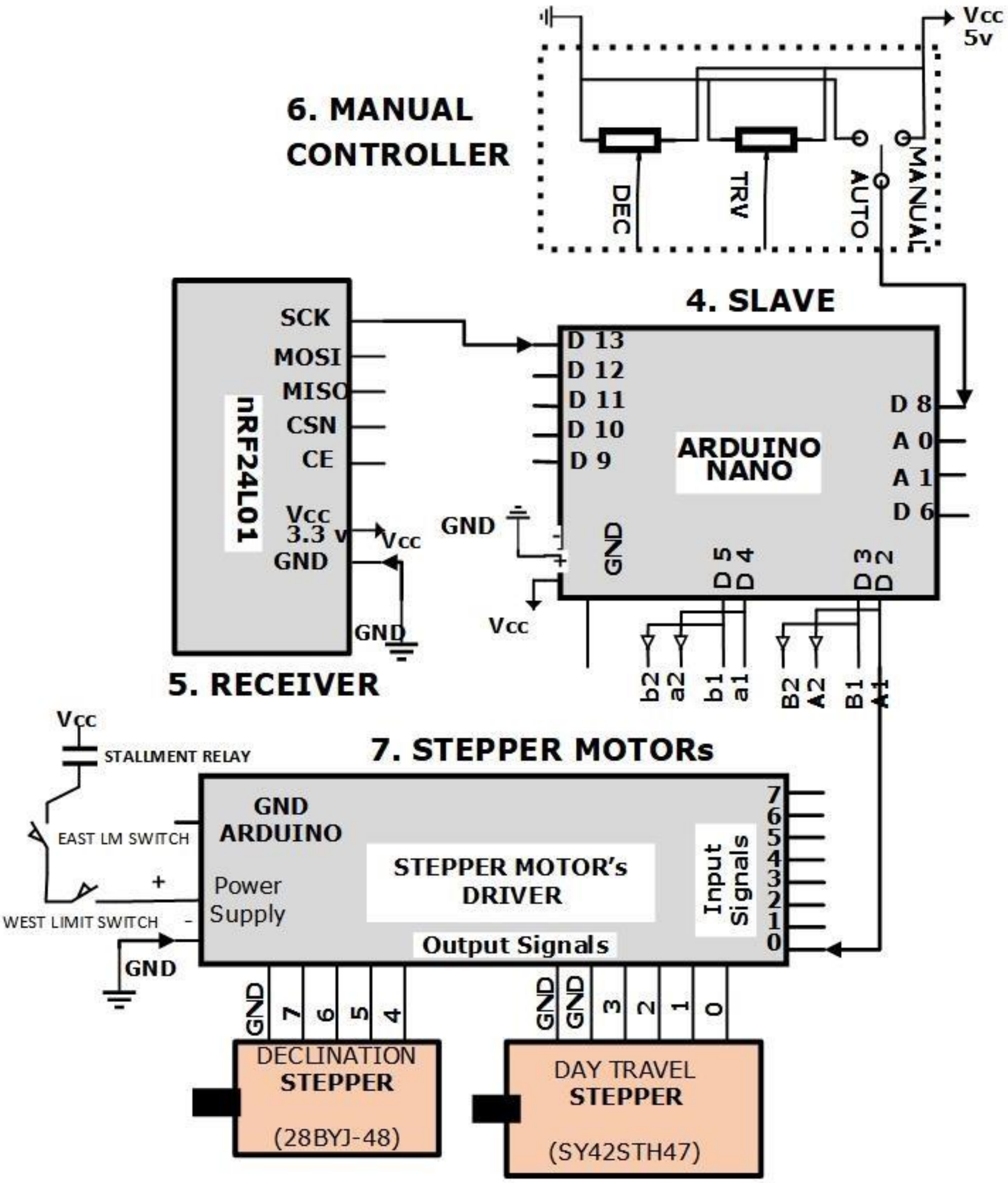

FIG. 5 – CIRCUITRY AT THE MACHINE LEVEL

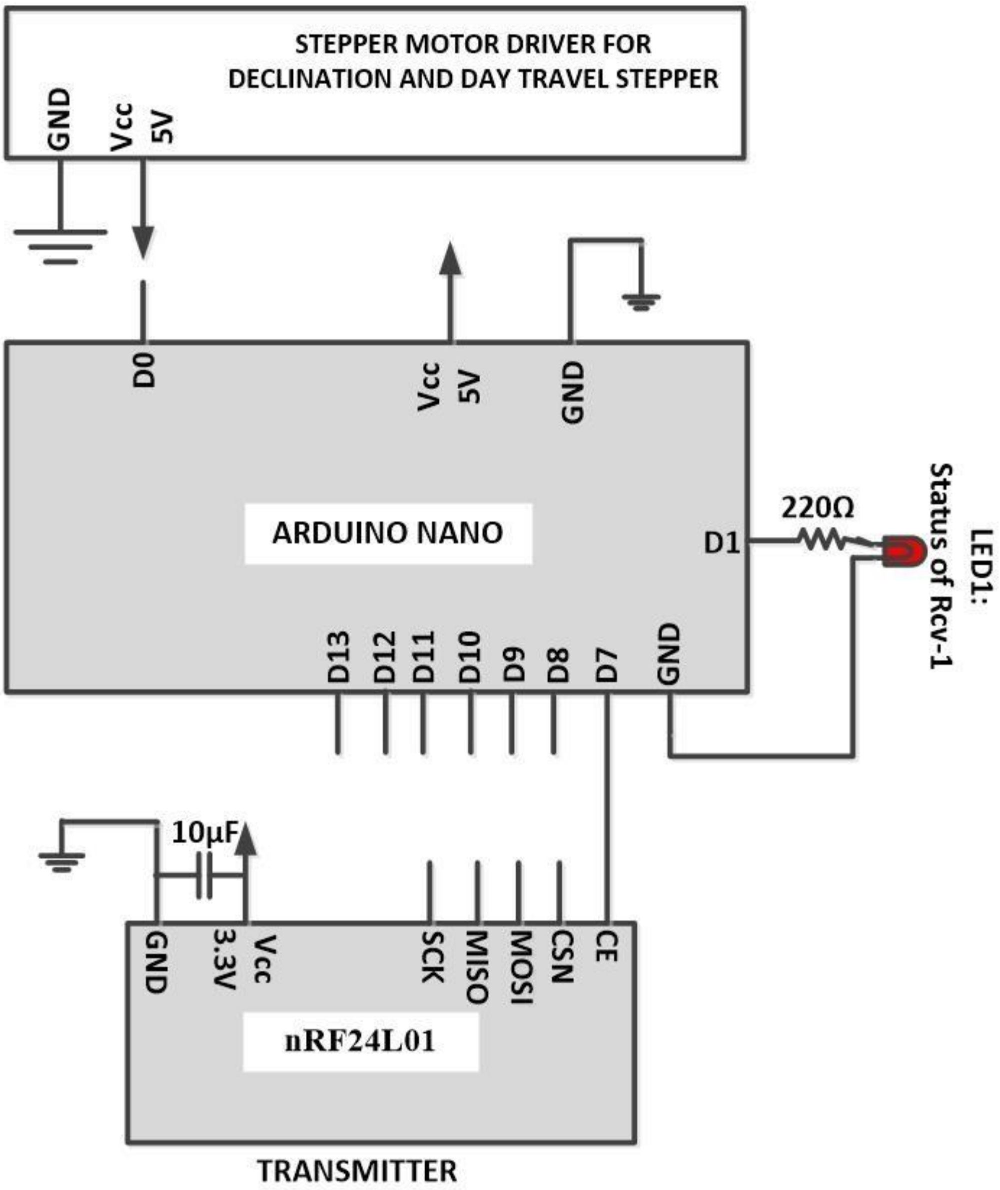

FIG-6: FAULT DETECTION AND TRANSMITTING UNIT-1

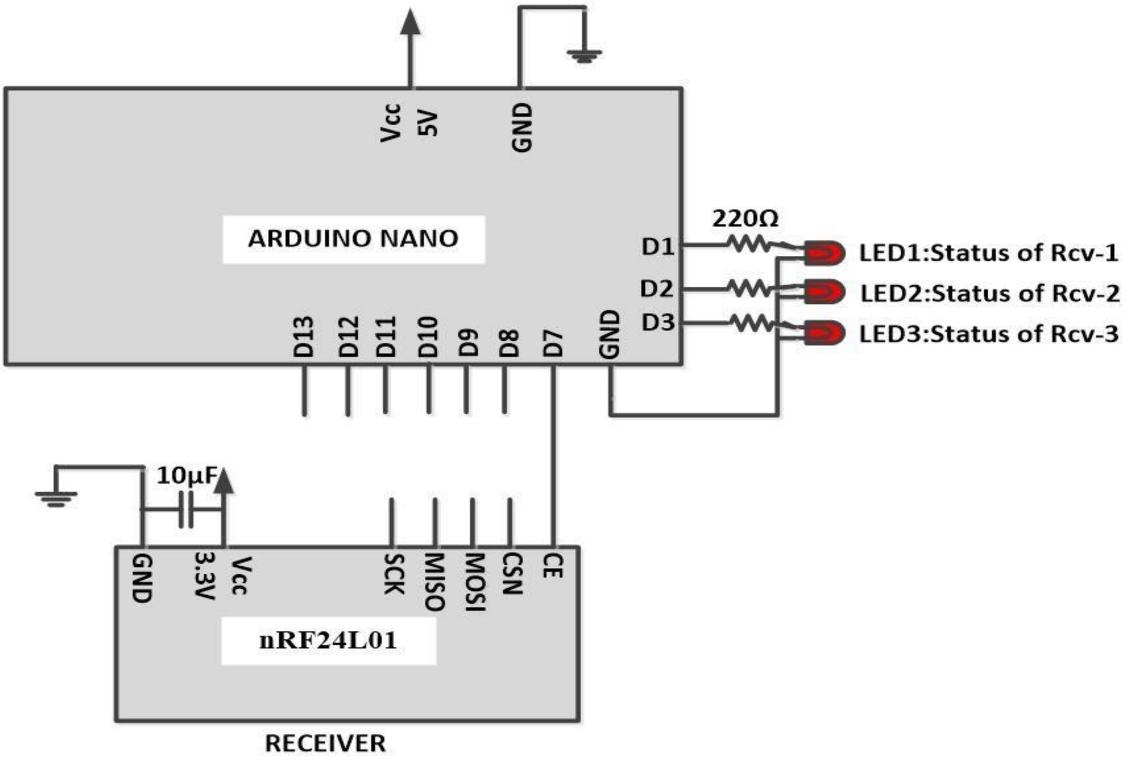

FIG-7: CONTROL ROOM FAULT MONITORING(RECEIVING) UNIT

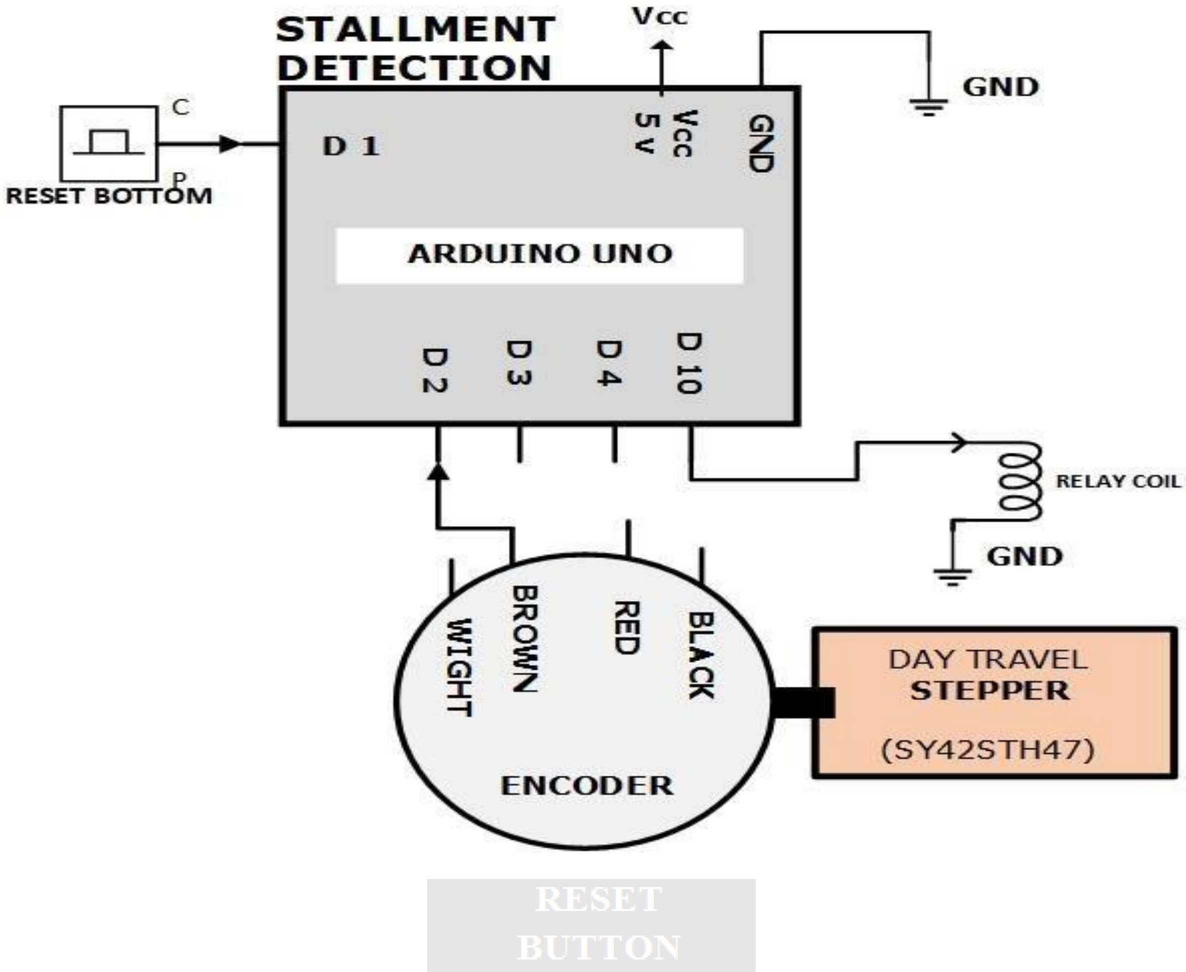

FIG. 8 – A CONTROLLER, RELAY AND RESET BUTTON RELATED TO THE ENCODER

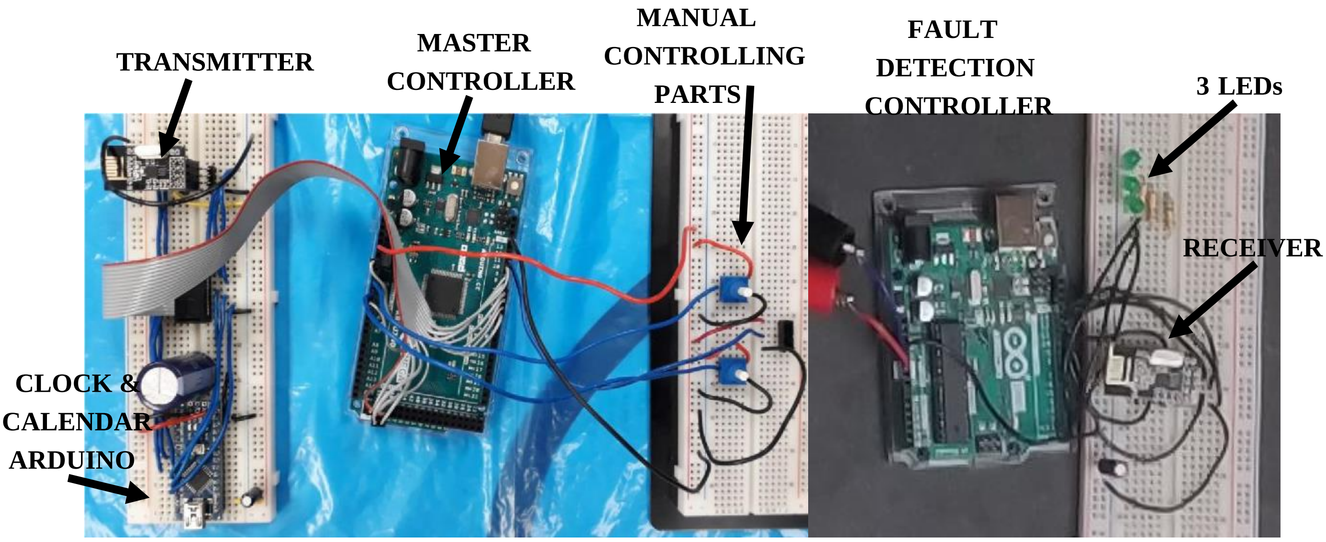

FIG. 9 - A PHOTOGRAPH OF THE EXPERIMENTAL SETUP – MAIN CONTROL ROOM

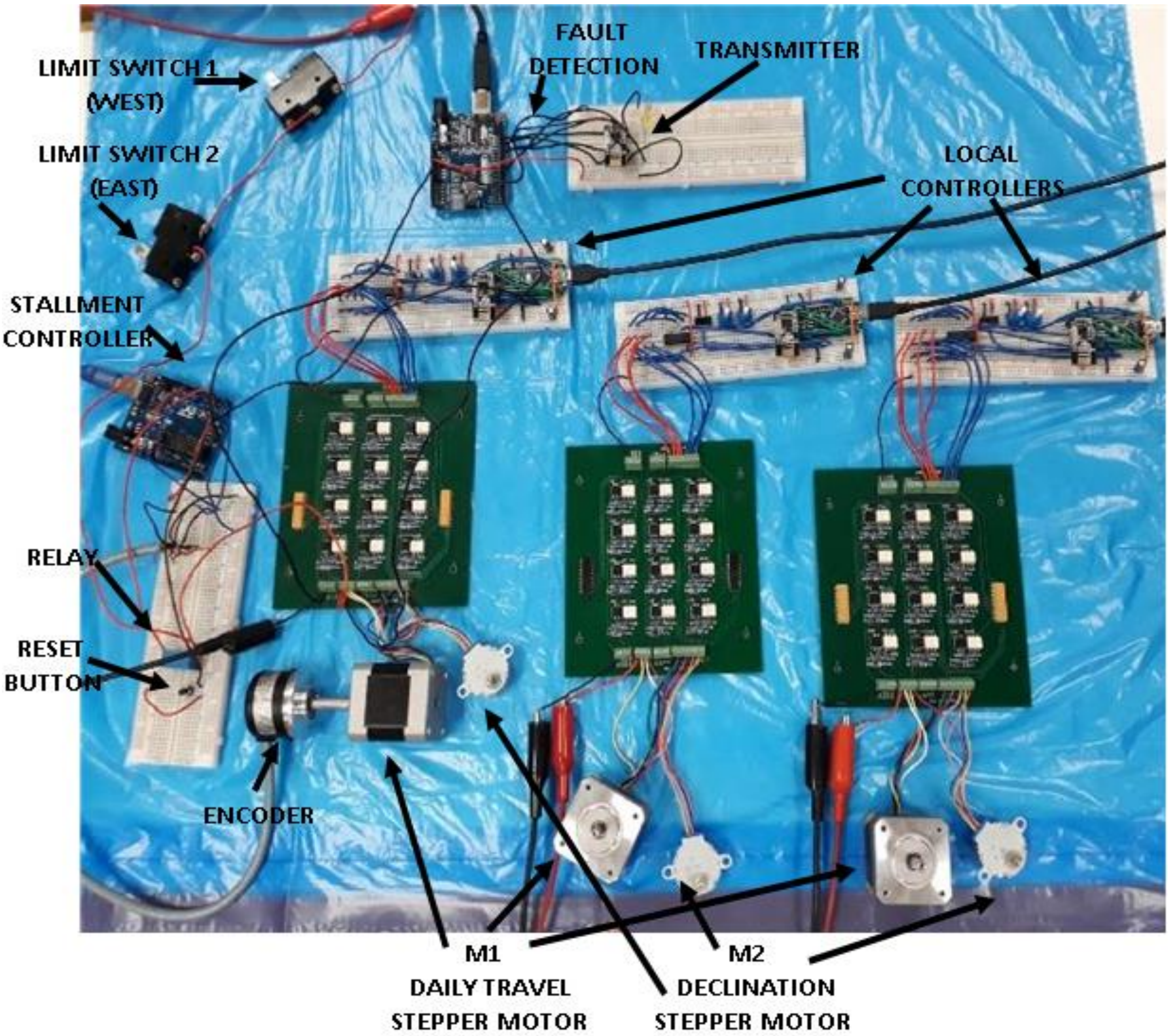

FIG.10 A PHOTOGRAPH OF THE EXPERIMENTAL SET-UP WITH INDIVIDUAL MACHINES

Table 1 - Wire Connections in FIG. 4

ARDIO MEGA pins (1. MASTER)	ARDUINO NANO pins (2. TIME)	Nrf24l01 pins (3. TRANSMITTER)	MANUAL CONTROLLER
D10	D10		
D 9	D9		
D 8	D 8		
D 7	D 7		
D 6	D 6		
D 5	D 5		
D 4	D 4		
Analog 3	PWM 3		
D 48		CE	
D 49		CSN	
D 50		MISO	
D 51		MOSI	
D 52		SCK	
D 11			Switch
A 0			PotentiometerTRV
A 1			PotentiometerDEC
Vcc (5 v)	Vcc (5 v)	Vcc (3.3 v)	Vcc (5 v)
GND	GND	GND	GND

Table 2 - Wire Connections in FIG. 5

ARDIO NANO pins (4. SLAVE)	Nrf24l01 pins (5. RECEIVER)	(6. MANUAL CONTROLLER)	(7. STEPPER MOTORs)
D 9	CE		
D 10	CSN		
D 11	MOSI		
D 12	MISO		
D 13	SCK		
D 8		Switch	
Analog 0		Potentiometer-TRV	
Analog 1		Potentiometer-DEC	
A1			In 0
B1			In 1
A2			In 2
B2			In 3
a1			In 4
b1			In 5
a2			In 6
b2			In 7
Vcc (5 v)	Vcc (3.3 v)	Vcc (5 v)	Vcc (5v) connected to the terminal of the relay
GND	GND	GND	GND

Table 3 - Wire Connections in FIG. 6

STEPPER MOTOR DRIVER FOR DECLINATION AND DAY TRAVEL STEPPER	ARDIO NANO pins	nRF24L01 pins (TRANSMITTER)	LED	REMARKS
Vcc (5 v)	D0			
	D 1		LED Anode leg is connected with 220 Ohm Resistor	Status of Rcv-1 (if fault, flashing)
	D 7	CE		
	D 8	CSN		
	D 11	MOSI		
	D 12	MISO		
	D 13	SCK		
	Vcc (5 v)	Vcc (3.3 v)		
	GND		LED Cathode leg is terminated	Status of Rcv-1 (if fault, flashing)

Table 4 - Wire Connections in FIG. 7

ARDUINO NANO pins	nRF24L01 pins (RECEIVER)	LED	REMARKS
D1		LED1 Anode leg is connected with 220 Ohm Resistor	Status of Rcv-1 (if fault, flashing)
D2		LED2 Anode leg is connected with 220 Ohm Resistor	Status of Rcv-2 (if fault, flashing)
D3		LED3 Anode leg is connected with 220 Ohm Resistor	Status of Rcv-3 (if fault, flashing)
D7	CE		
D8	CSN		
D11	MOSI		
D12	MISO		
D13	SCK		
Vcc (5 v)	Vcc (3.3 v)		
GND		LED1, 2 & 3 Cathode leg is terminated	Status of Rcv-1, 2 & 3 (if fault, flashing)

Table 5 - Wire Connections in FIG. 8

ARDUINO UNO	ENCODER PINS	CONTROLLING PARTS
D 1		RESET BUTTON
D 2	BROWN	
D 3	RED	
D 4		FROM D6 PIN OF ARDUINO NANO IN LOCAL MACHIN
D 10		RELAY COIL
Vcc (5 v)	WHITE	
GND	BLACK	