DETERMINING DE-RATE FACTORS OF PHOTOVOLTAIC SYSTEM IN CONSIDERATION OF THE PHILIPPINE SETTING TO ACHIEVE OPTIMIZED EFFICIENCY

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ABSTRACT

For the past years, there has been so much increased on the use of the solar energy. The advantages of the photovoltaic system are the absence of the greenhouse gas emission, very low maintenance cost, the absence of mechanical noise, and with minimal limitations regarding the site installation. Photovoltaic system are especially well suited to locations where accessing an electrical grid is either not feasible or expensive. It has proven a reliable source of power in an ever-growing number of applications, especially in the residential. The electrical energy demand coming from the stand-alone photovoltaic system is dependent on its payback period and the parity price of its generated power to the electrical utility. Also, with all these advantages cited, the PV system is suffering from a relatively low efficiency. A reliable method for sizing to achieve optimized efficiency is a certainty. The method should be very sensitive from the very simple but reliable to the most complex models for the stand-alone PV system. This paper identifies the de-rate factors of the PV system taking into account the Philippine setting. This also includes the review on the significant information to be taken into account during the design and upon the implementation of the system.

Keywords—renewable energy; solar energy; photovoltaic system; de-rate factor

Introduction

The harnessing and utilization of renewable energy comprises a critical component of the Philippine government's strategy to provide energy supply for the country. This is evident in the power sector where increased generation from solar, geothermal and hydro resources has lessened the country's dependency on imported and polluting fuels. It is the government's policy to facilitate the energy sector's transition to a sustainable system with renewable energy as an increasingly prominent, viable and competitive fuel option. The shift from fossil fuel sources to renewable forms of energy is a key strategy in ensuring the success of this transition.

Renewable energy is important for different reasons. Renewable energy is not subject to sharp price changes because it comes from sources such as sunshine, flowing water, wind, and biological waste, all of which are free. This gives people greater certainty about the cost of energy, which is good for society and the economy. By comparison, fossil fuels are limited in their supply, and their price will increase as they become scarcer. Renewable energy adds very few pollutants to the environment making it a clean and green technology. It does not release carbon dioxide, which is the major cause of global warming. It has a very little impact on land use. It has unlimited supplies of fuel. And it can be developed in such a way that every household or neighborhood could have its own renewable power generating equipment. This would create many new jobs for people involved in setting up and maintaining this energy supply, and in manufacturing the equipment. It is also more efficient to produce renewable energy in small amounts right where it is needed [1].

Solar energy is a very promising alternative energy due to its inherent characteristics: non-pollution, renewable, enormous amount, etc. It has been intensively studied during past decades, particularly after the 1970s energy crisis. The worldwide intensive researches on solar energy, especially on photovoltaic conversion have significantly reduced the costs of solar cells and modules as well as markedly increased the reliability of photovoltaic systems. At the present time, photovoltaic is already competitive compared with diesel generators in lighting, water pumping, refrigeration of vaccine, etc. in areas where no utility is available.

The photovoltaic (PV) system is an electrical power generating system that uses solar energy to produce electrical energy. The PV systems are designed to supply electrical energy to any type and size of electrical load. The major components of the PV systems are the photovoltaic array or panel, energy storage devices, power conditioning system, and electrical loads. There are two types of PV system, these are stand-alone PV system and interactive PV system. The stand- alone PV system is independent of any other electrical system and the interactive PV system is operating in parallel and is synchronized and interconnected with the electric utility grid [2].

The PV system can be considered superior among other renewable energy types as there is no depletion issue to this case and with no direct pollution issue as the system is only dependent on the solar irradiance. Thus, the PV system is a very promising application for large-scale generation of electricity. This PV system is also potentially applicable in a wide scale application in the Philippines as an estimated area of 250 by 250 km^2 PV station can meet the global electricity necessity in the year 2020. In line with this, a thorough understanding of the operating performance of the PV system in a real weather condition is essential for the designer of the system [1]. The need to optimally capture the solar energy and the improvement of the overall performance of the system should always be accounted for [3].

Also, regardless of the method used to size a stand-alone photovoltaic system, a thorough knowledge of the availability, performance, and cost of components is the key to good system design. When starting the design, obtain as much information about the components to be used. Price/performance tradeoffs should be made and re-evaluated throughout the design process. The design should assure customer satisfaction by providing a well-designed, durable system with a 20+ year life expectancy. This depends on sound design, specification and procurement of quality components, good engineering and installation practices, and a consistent preventive maintenance program.

Over the years, researches have been conducted that aimed to develop simulation model for the PV system in a real weather condition. The design should always emphasize on upgrading the efficiency of the power conversion, lowering the cost of the PV system, and improving the reliability of the system. The efficiency of the system can be affected by the temperature, sunlight's spectral characteristics, insolation, degradation of the array, location, and the likes [4]. The accuracy and complexity for practical application requires detailed information as to the location of the system to develop optimized efficiency. A comprehensive literature review and identification of the factors affecting the performance of the PV system are the main contribution of this paper.

II. SITE CONSIDERATION AND CALCULATION OF PANEL ANGLE

The stand-alone photovoltaic system should be properly specified and installed, that would result in a system that operates to its design potential. The efficiency of PV will depend on the maximum sun exposure, so the site is very important. Less solar energy will result to less electricity; and, more solar energy will result to more electricity. To get the most from solar panels, it is necessary to point them in the direction that captures most sun. And that, photovoltaic panel should have a complete exposure to sunlight from 8am to 4 pm. There are a number of variables in figuring out the best direction.

In [5], the experimentation intended to identify the efficiency of three different situation of the PV system. These were modules with tracking mechanism, modules with stationary frame, and modules mounted on the southern wall. It was found out that there was no correlation of any of the situations to the power generated of the system. The first may have the most efficient performance throughout the year but the later situations were efficient also in some of the months of the year. The experimentation concluded that the electricity production of the PV systems were very dependent to the intensity of the solar irradiation and the average air temperature of the location.

Site consideration should be an open space to give better heat gain to the modules. There should be no tall trees that may produce shading to the panel, thus lessening the performance of every panel. Site should not be accessible by public and animals that may cause damage to the panel. And, the site should be able to accommodate complete exposure to sunlight for at least 6 hours a day. Books and articles on solar energy often give the advice that solar panel should always face south and the tilt should be equal to the latitude of the site.

If the module is to be kept perpendicular to the sun's daily east to west motion, then, a calculation of panel angle should be implied. The calculation of the panel angle (A) is based on the supposition that the panel will be perpendicular to the sun's rays at solar noon. Solar noon is the time when the sun is the highest in the sky. This calculations involved two parameters; the latitude of the site (L) and the declination of the sun (D). The declination of the sun can be computed using equation (1):

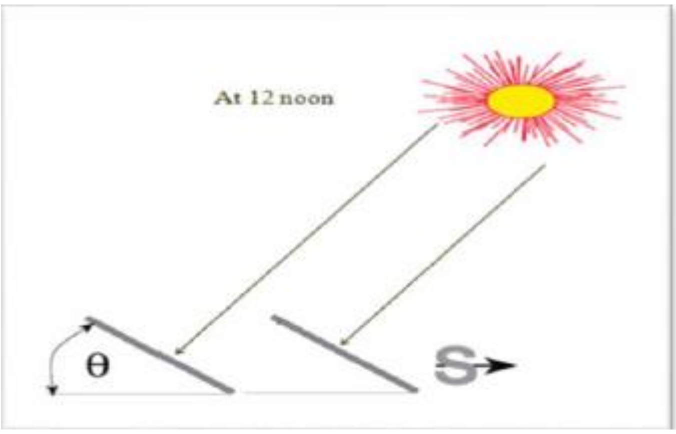
$$D = 23.5^{O} \sin\left[\frac{T}{365.25}\ x\ 360^{O}\right] \qquad (1)$$

where T is the number of days as measured from spring equinox. The panel angle (A) or the angle between the panel and the horizontal plane is then calculated using equation (2):

$$A = L - D \quad (2)$$

The figure 1 shows the panel orientation. The panel should be facing the south and the panel angle should lead to direct perpendicularity of the panel to the sun at 12 noon.

Fig. 1 Panel orientation and panel angle



In a series of PV arrays, the shadows of the front arrays, considering the computed tilt angle, will give an impact on the output of the arrays just behind them. The efficiency of the system decreases by 20% if the shading factor is ignored. In [6], the formula for the solar declination angle is given by equation (3):

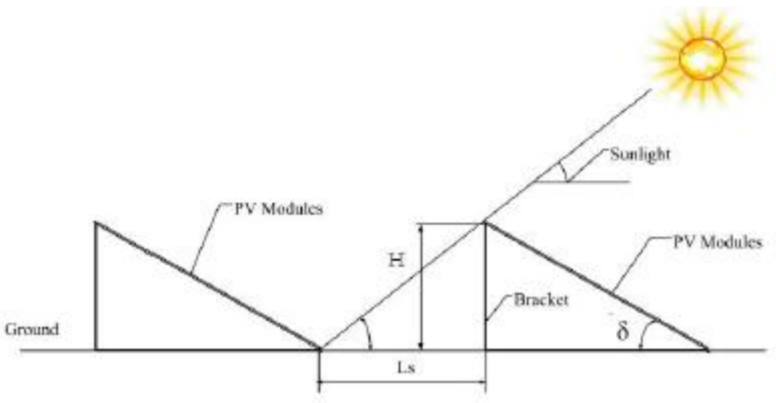
$$\delta = 23.45 \sin\left[360\ x\ \frac{284+n}{365}\right] \qquad (3)$$

where n is the date with January 1 equal to one. The formula is applicable if the panel is equipped with tilting mechanism. The different tilt angles have also different spaces (Ls). The space is necessary to avoid the shading coming from the shadow in front and to eliminate the 20% de-rate factor out of this shading factor. The Ls can be computed using equation (4):

$$L_S = H\ x\ cot(90 - |\emptyset - \delta|) \qquad (4)$$

where H is the mounting height of the panel and ∅ is the local latitude. Figure 2 shows the layout of the PV modules taking into account the spacing of every panel.

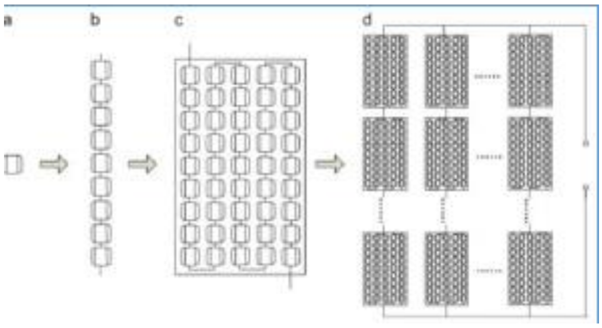
Fig. 2 Layout of the photovoltaic modules



III. DE-RATE FACTORS OF PHOTOVOLTAIC ARRAY

The PV cell interconnected in series and forming the cell series string is the basic unit of the PV system. The composition of one or more strings is formed to produce PV module. The PV modules are connected in series to increase the voltage output of the system, and, in parallel to increase the current output of the system. A photovoltaic array is a linked collection of photovoltaic modules, which are in turn made of multiple interconnected solar cells. Figure 3 shows the units of the PV system [1]. The peak power of the chosen solar panel will not be produced as specified. There are de-rates factors that need to be consider that perceive the actual condition of the array once it is installed.

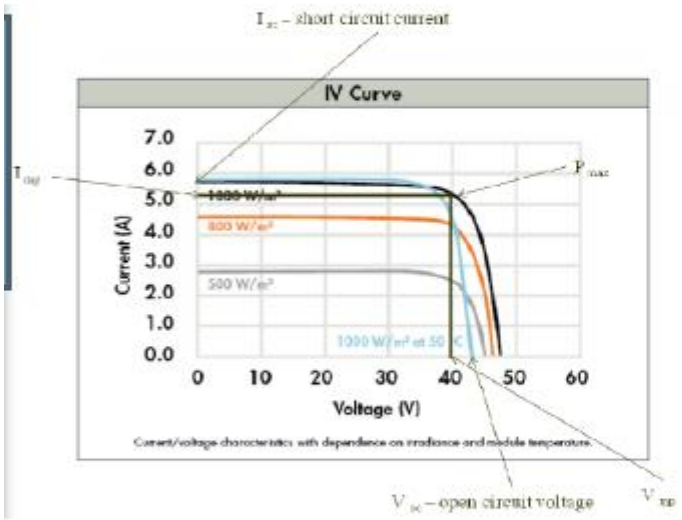
Fig. 3 PV system unit from a photovoltaic cell (a) to cell series string (b) to PV module (c) to PV array (d).



The output of the solar modules is evaluated by the manufacturers using the Standard Test Conditions (STC). The STC of every module should also include the open-circuit voltage (Voc), the voltage at the maximum power point (Vmp), the short circuit current (Isc), the current at maximum power point (Imp), the maximum power at STC (Pmax), the number of cells connected in series, and, the temperature coefficient of the Voc and Isc. Studies show the nonlinearly dependence of the PV system voltage to the irradiance level, but there is a linear relation between the irradiance and the PV current [7] [8].

The maximum power of the solar cell will always depend on the radiation intensity, the ambient temperature, and the load impedance. To enable the attainment of the maximum power and to ensure the efficient operation of the cell, identification of the PV output voltage and/or current under a given temperature and irradiance should always be accounted for [9]. The IV curve is always provided by the supplier of the panel to better understand the functionality of these. Figure 4 shows a sample IV curve of a PV panel. It clearly displays the linear relation of the current to the solar irradiance.

Fig. 4 Current/Voltage curve



With the consistent comparison of the different products, it is necessary to identify the solar cell temperature and the solar irradiance of the place to where the system will be installed. Each module is always given a production tolerance of ±5% but it is always safe to use the low end of the output spectrum [10].

A. Temperature De-rate Factor (k_1)

Module output power reduces as module temperature increases. When operating in direct sunlight, a solar module will heat up substantially, reaching inner temperature of 40 ^{O}C to 70^{O}C. Likewise, a reduction factor of 89% is recommended by the STC[10]. The atmospheric temperature of the site will also vary from time to time. Temperature de-rate factor (k_1) is determined using the equation (5):

$$\boldsymbol{k_1 = 1 - 0.00(\theta_t - \theta_s)} \quad (5)$$

where θ_t is the tested operating condition of the solar panel and θ_S is the atmospheric average temperature per month of the site. Thus, the temperature de-rate factor of the array is 15%, considering the average temperature tested operating condition of the solar panel and the average atmospheric temperature in the Philippines.

B. Reflection De-rate Factor (k_2)

When designing a photovoltaic system, site should be free from shading. A narrow shadow from a nearby surroundings partially covering only one module can actually reduce the total array output up to half. But no matter how isolated the site is from shadows, clouds and fogs should be anticipated since the two produce shading. A cloudy day and a foggy environment would result to a lesser heat intensity coming from the sun, thus affecting the output of the panel. A 2% compensation factor should be implied in designing a photovoltaic system.

C. Partial shading, Dust and Dirt De-rate Factor (k_3)

Condition of the partial shading, mostly caused by the clouds and the nearby tall trees and buildings, is one crucial issue that is inevitable. The sun irradiance level becomes unreliable and inconsistent when the sun is blocked by the abovementioned. The shaded cells can get reversed bias, thus, producing high resistance and consuming more power and in turn reducing the load current. The connected diodes are only intended to protect each cell and not to increase the efficiency of the system when shading occurs. The shading will also result to nonlinearity to the current/voltage (IV) curve [4].

Another inevitable issue that the PV system is facing is the dust and dirt. Dirt and dust accumulate on the solar module surface, and this results to blocking some of the sunlight and reducing the output [11]. Although, typical dirt and dust are cleaned off during rainy season, it is realistic to estimate the system output taking into consideration the reduction due to dust build-up in the dry season. A typical shading, dirt and dust de-rate factor is 2%.

The equation (6) is used for the determining the output of the array in kilowatt is:

$$\boldsymbol{P_{Array}} = \boldsymbol{R_S} \; \boldsymbol{x} \; \boldsymbol{P_{Max}} \; \boldsymbol{x} \; \boldsymbol{k_{Array}} \quad (6)$$

where PArray is the output of the photovoltaic array in kilowatt; PMax is the rated peak power of the panel in watts; and kArray is the de-rate factors of the array considering all the mentioned de-rates factor.

Considering the Philippine setting with a solar irradiance of 4.50 kWh/m2 per day and 6 hours of complete exposure of the panel to sun, the de-rate factor of the array is 81.634%. A typical 100W panel, when subjected to the de-rate factors of the photovoltaic panel and using the formulas abovementioned,
this will only produce 61.22 watts. The computation shows the flow of the conversion from 100 watts to 61.22 watts.

$$P_{array} = \frac{4.50 \frac{kWh}{m^2}}{6 \; hrs} \; x \; 0.1 \; kW \; x \; (1 - 0.15) x \; (1 - 0.02) x \; (1 - 0.02)$$

$$P_{array} = 0.0612255 \; W \; Or \; 61.2255 \; W$$

IV. DE-RATE FACTORS OF THE BATTERY OUTPUT

A battery in a photovoltaic system is a device that stores electrical energy (converted radiant energy from the sun by the PV module) in the form of chemical energy during charging. The chemical energy is then converted to electrical energy during discharge.

A. Battery Charging Efficiency (k_4)

Battery is one of the most critical parts of a photovoltaic system. The connections and wiring of the batteries plays a large role in how well the batteries are treated. The quality and method of wiring these systems is very important to maintain acceptable battery health and lifetime. A flooded cell lead acid storage battery should have at most 50% depth of discharge and at least 75% state of charge. Failure to do such will lessen the life span of the battery and reduce its capacity.

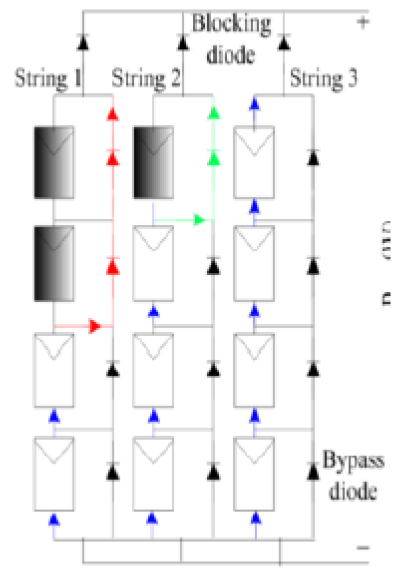
Other battery problem includes sulfation, this happens due to deep discharge condition and that the sulphur combines with lead and coats the plates; treeing or the misalignment of plates and separator resulting to short circuit between plates; and moosing or the buildup of materials on top of the battery elements. Normally, the de-rate factor of battery is 20%.

B. DC Circuit Efficiency De-rate Including By-pass and Blocking Diode (k_5)

Solar modules produce dc electricity. The dc output of solar modules is rated by manufacturers under Standard Test Condition (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions.

A practical way of arranging the PV array is the inclusion of two diodes. The bypass diode, connected in parallel, which is intended to protect the modules from hot-spot. The hot-spot normally happens when the number of series connected PV cells and modules are less illuminated and the module behaves as load instead of generator. The other diode is the blocking diode which is connected at the end of the PV string. This diode intends to protect the array from the current imbalance between every string [3] [11]. Figure 5 shows the connection of the two diodes to the PV system.

Fig. 5 Bypass and blocking diode connection to the PV system



Blocking diode specifically prevents reverse current in case a string has a damaged module. It is normally required when the array produces 48 volts or more. There is a loss of 0.5 – 0.6 volts threshold voltage of the diode. Thus, a de-rate factor of 1% for the DC circuit efficiency should be implied.

C. Compensate Factors for Mismatch and Wiring Losses (k_6)

The maximum power output of the total photovoltaic array is always less than the sum of the maximum output of the individual modules.

Due to the difference of the sum of the maximum output of each panel and the maximum power output of the total PV array, this results to slight consistencies. These consistencies are related to the performance of one module to the next and is termed module mismatch. Also, the factor of resistance produced by the wiring system should be considered.

This difference is a result of slight inconsistencies in performance from one module to the next and is called mismatch and amounts to at least 5% loss in system power. A reasonable reduction of 5% as mismatch and wiring losses should be accounted when designing a PV system.

A total of 67.32% as the compensating factor for the battery output should be considered

V. DE-RATE FACTOR OF THE INVERTER (K_7)

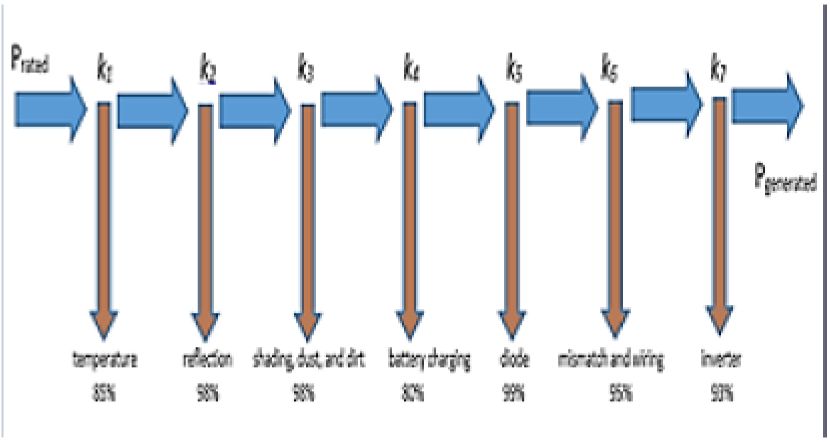
Since the solar produces DC power and the electrical loads in the Philippines are mostly designed to perform at an alternating current source, it is necessary to include an inverter to the system. The efficiency of the inverter is the measurement of the usable AC current that comes out of the equipment. This efficiency will vary on the amount of power consumption per given time. The peak efficiency of the inverter is normally in the 93% to 96% range and these are measured under the well- controlled factory conditions. But, in the actual field of conditions, it is a reasonable compromise to use 93% conversion efficiency of dc to ac.

VI. OVER-ALL DE-RATE FACTOR OF THE SYSTEM

When designing a stand-alone photovoltaic system, it is not advisable to rely on mere predictions and estimations. Formula for sizing the photovoltaic array, for determining the capacity of the battery, the rating of the inverter and others are provided to make the design closer to accuracy.

A total of 42.88% comprising of 18.366% from the array and 30.0268% from the electrical equipment is the over-all de- rate factor of one panel or the whole system. A 200-W power rated solar panel, considering all parameters in good conditions and with complete exposure to sunlight for at least 6 hours, will only produce 102.22 watts per day. The de-rate factors may vary depending on the parameters cited but it is ideal to use the specified factors. Figure 6 shows the power stage of the PV system with the common losses out of the de- rate factors.

Fig. 6 Power stages of the PV system



VII. Conclusion

Photovoltaic system are especially well suited to locations where accessing an electrical grid is either not feasible or expensive. It has proven a reliable source of power in an ever- growing number of applications, one of which is lighting streetlights.

Photovoltaic system offers many advantages making this the best option among other renewable source of energy. A well designed photovoltaic system will operate unattended and requires minimum periodic maintenance. Thus, the savings in labour and maintenance costs are very significant. A photovoltaic system can be designed for easy expansion. If the power demand might increase in future years, there is no need to replace the existing components. Solar energy, being its main fuel, is free. It does not create pollution or waste products.

System designers know that every decision made during the design of a photovoltaic system affects the cost. If the system is oversized because the design was based on unrealistic requirements, the initial cost is increasing unnecessarily. If less durable parts are specified, maintenance and replacement costs are increased. The overall system life span estimates can easily be decreased if inappropriate choices of equipment and components are made during system design. As the photovoltaic system is sized, be realistic and flexible and not rely on poor assumptions and unrealistic specifications. Equations in sizing the system are made to make the design more accurate and precise.

Availability has a distinct meaning for a photovoltaic system. It depends not only on reliable equipment but on the level and consistency of sunshine, and the capability of the energy storage system. Because weather is unpredictable, designing a system to be available for all times is not advisable. Instead, specify days of autonomy by studying the topography of the site. This may double or triple the size of the system, but if it is the only source of electrical energy, then it must be applied.

The power output of a photovoltaic array is maximized by keeping the array pointed at the sun. The tilt angle of the solar panel depends on the latitude of the site. Thus, study and analyze the long-term solar data of the projected location of the system to maximize the production and performance of the system.

A well designed and maintained photovoltaic system will operate for more than 20 years. The most system problems occur because of poor installation which includes failed connection and insufficient wire size; the next most common cause of problems is the failure of the electronic parts of the controller, inverter, and protection components.

A well designed stand-alone photovoltaic system with 20 plus year life expectancy is due to sound design, specification and procurement of quality components, good engineering and installation practices, and a consistent preventive maintenance program

VIII. Acknowledgement

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