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Renewable Energy Performance of the Green Buildings: Key-Enabler on Useful Consumption Yield

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ABSTRACT  Malaysia’s Eleventh Plan started to encourage green building developments and green industries to stimulate green growth. Eventually, the Malaysian government had launched a new commitment to accelerate the green and efficient energy sector and revised the quota of Renewable Energy (RE) towards higher capacity for electricity generation. These scenarios had highlighted the latest commitment of the Malaysian government to implement both green building development and concurrently, streamline the additional quota for RE generation. Due to this, the evolution of the requirement of RE-based Distributed Generation (DG) in the green building development for higher installed-capacity was expected to occur in ensuring the government key achievement becomes more visible. This study focuses on measuring the expanded-capacity performance of the Solar Photovoltaic (PV)-type DG unit (PV-DG) through the Green Building Rating System (GBRS), particularly on the useful energy consumption yield for load and total line loss minimization. Previous work has conducted a MATLAB simulation on a PV-DG capacity expansion guided by the Net Energy Metering (NEM) specification considering the total line loss minimization as the main objective function. These results are being adopted to obtain the ratio of useful energy consumption from the generated PV-DG through the selected distribution network. Consequently, the Performance Ratio (PR) - as the internationally recognized formulation for a complete PV-DG system - is proposed to be revolutionized towards extended version, considering the specific total line losses minimization, via the formed of the proposed ratio.

INDEX TERMS  Green building rating system, net energy metering, distributed generation, payback period, performance ratio.

I. INTRODUCTION  Global environmental issues have introduced a climate change as an important topic which prioritized the emission of greenhouse gas (GHG) as well as the carbon dioxide (CO2) and protecting the global environment as a major control measure [1]. Any attempt to combat global warming critically depends on China’s trajectory growth in terms of the distinct drivers of domestic CO2 emissions since China is now known today as the largest single emitter...
of CO₂ [2]. The understanding of drivers for CO₂ emissions underlies the stemming from the burning of fossil fuels and the manufacture of cement including the produced during consumption of solid, liquid, gas fuels and gas flaring which is critical for economic and environmental sustainability [3]. This also includes the emissions produced by ocean-going vessels not only negatively affect the environment but also may deteriorate the health of living organisms, whereas several regulations were released by the International Maritime Organization (IMO) to alleviate negative externalities from maritime transportation [4]. This seen of importance where Abioye et al. [5] had highlighted that more than 80% of the global trade tonnage and 70% of the global trade value are carried by oceangoing vessels around the world according to the United Nations Conference on Trade and Development (UNCTAD). Besides, CO₂ emissions from maritime transportation constitute approximately 2.2% of the overall world anthropogenic carbon dioxide emissions [6]. On the other hand, the global aviation industry had counted for over 3 billion air passengers, which produced 705 million tons of CO₂ in 2013 with 2% of the human-induced CO₂ emissions and 13% of total transportation-related emissions as according to the Air Transportation Action Group (ATAG) [7].

Various studies on the relationship between CO₂ emissions and their main drivers for different individual countries have been conducted, where Mikayilov et al. [8] highlighted these studies which include Russia [9], Turkey [10], Spain [11], France [12], Canada [13], China [14], India [15], and for Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, and South Africa [16]. In Malaysia context, sustainability has been formally embraced in Malaysia Eleventh Plan where green growth is set as a fundamental shift especially in the human capital, policy, and regulatory framework, green technology investment, and financial instruments [17]. In line with the said initiative, [17] also highlighted that the Ministry of Energy, Green Technology, and Water (now known as Ministry of Energy, Science, Technology, Environment and Climate Change Malaysia (MESTECC)), will advance the development for green products and services in the domestic market. Measures to be undertaken include implementing Government green procurement for at least 20% by year 2020, encouraging the green building developments and industries greening to stimulate green growth. Moreover, due to environmental factors and conflicting in the price of oil at the international market, the concept of low energy building and green building are emphasized by the Malaysian government [18].

Consequently, the green and efficient energy sector in Malaysia has set a 2% share of RE installed-capacity in the previous year (before 2015) while targeted for 5.5% by the year 2015 and finally striving towards 11% of standing quota to be achieved by 2020 [19]. In line with that, the Feed-in Tariff (FiT) implementation which has been commenced from 1st December 2011 has foreseen the uprising RE quota towards 17% by 2020 [20]. However, the most recent, MESTECCs’ 2019 initiative has launched a commitment to enlarge the green and efficient energy sector by increasing the percentage of RE from 2% towards 20% for electricity generation by 2025 [21]–[23]. These scenarios highlight the latest commitment of the Malaysian government to implement both green building development for government facilities and concurrently, streamline the additional quota for RE distributed generation (DG).

Furthermore, Amran et al. [24] has highlighted the encouragement for RE utilization through scoring credit in main assessment criteria among the selected Green Building Rating System (GBRS) originated from Southeast Asian Countries (ASEAN), i.e. Malaysian Carbon Reduction Environmental Sustainability Tool (MyCREST), Green Building Index (GBI) Malaysia, GreenRE Malaysia, Green Ship Indonesia, Thai’s Rating of Energy and Environmental Sustainability (TREES) and Green Mark Singapore [25]–[30]. In addition, GBRS originated from United State of America (USA) i.e. Leadership in Energy and Environmental Design (LEED v4), has also been considered into the list due to its remarks as the pioneer and the great influencer for newer GBRS throughout the world [31]. The intent of the RE assessments from these selected GBRS has been concluded towards prioritizing, encouraging, acknowledging effort in utilizing RE and reducing environmental impact approaches. This has portrayed the current imposed of small scale RE category as referred to their respective assessment criteria concerning the current maximum demand (MD) [24]–[30], [32]. In conjunction with the above-mentioned commitment by MESTECC towards 2025 as accordance to Amran et al. [33], the growth in RE-based DG is significantly being enabled towards higher installed-capacity, in ensuring the government key achievement can be visibly fulfilled.

The previous work [33]–[37] has overcome various kinds of optimization techniques in determining the PV-DG sizing and placement guided by the total line losses as the main objective function. However, the significant key-findings from the total line loss and performance outcome among these selected references towards the more accurate payback period outcome was not highlighted, thus, leaving a gap for justifying the role of both total line loss minimization and the higher performance factor towards their potential values to determine the payback period milestone. Since simultaneous optimization criteria for RE-based DG location and capacity was found to be more effective to be observed via minimal losses outcome [34] and also implemented in many recent kinds of literature [33]–[37], therefore, an extended assessment on this loss minimization and performance outcome towards monetary benefits need to be synchronized for more reliable and justified analysis in PV-DG measure as well as during early-stage design and estimation process.

The required evolution in the RE landscape as part of the green building criteria through GBRS is a focus of this study where the initial assessment is made to the current RE setting for measuring the technical and financial worth. In contrast, the impact of this factor also significantly determined the payback period for capital expenditure (CAPEX) and
operational expenditure (OPEX) milestone. Subsequently, adoption of the current scheme related to solar photovoltaic (PV) as DG (PV-DG) is made followed by a further assessment to identify the potential factor in rectifying the performance ratio (PR) towards extended version and justifies the PV-DG expansion-limit which best suit for the distribution network.

This paper proposes a measure for the ratio (i.e. $\varphi$) of useful energy consumption for load and loss minimization from the PV-DG generation which enables the formulation in obtaining a more precise value of useful energy consumption yield for load and loss minimization figure within the selected distribution network. This factor is also aimed to be brought forward as a potential factor in the final yield ($Y_f$) input parameter which significantly improves the PR towards extended version for a more accurate figure in terms of both performance and the beneficial impact on the payback period measure. The findings of this research will guide the green building development towards a better aim, effectiveness, efficient and more sensible approach through improved estimation in PV-DG design as well as payback period determination for CAPEX and OPEX in line with up-to-date government policies. To achieve the goal, the optimization outcome and the PV-DG expansion-limit baselines from [33] are selected as the raw input data for further payback period assessment which is explained in the later discussion. The reason behind the selection is that the outcome in [33] has introduced an expansion-limit which also facilitates an input parameter of PV-DG expand capacity via NEM scheme beyond the current GBRS base case which is factored-in the performance calculation.

The rest of this paper is organized as follows: Section II introduces a literature review that touches on issues related to PV-DG in GBRS (Sub-section A), describes brief explanations on the indices for PV-DG performance (Sub-section B) and the payback period assessment (Sub-section C). Besides, Sub-section D discussed the research gap and contribution of the study. Section III describes the methodology used and the problem formulation for the proposed solution. Section IV presents the results and discussions. Section V concludes the paper.

### II. LITERATURE REVIEW

#### A. GBRS – ISSUES RELATED TO PV-DG

Based on the essence of sustainable developments, the RE usage such as PV-DG is one of the most influentially common principles [38] and consequential approach in reducing the energy consumption in buildings [39] while having considered as a key component of green building-based design for electricity generation capability [40]. In particular, a comparison in the current RE assessment between selected seven sets of GBRS has been conducted in [24] which comprised of different tools within six ASEAN originated countries and one from USA respectively. These seven different GBRS namely, MyCREST, GBI, GreenRE, GreenShip, Green Mark, TREES and LEED v4 were holistically compared in terms of the intent/aim of RE application and to portray the current pattern of RE criteria setting including the scoring (credit) as shown in Table 1 and Table 2 respectively. Furthermore, three groups with the highest RE capacity requirement were identified via an empirical review in classifying their current RE assessment criteria in terms of the capacity requirement and scoring credit as shown in Table 3.

The recent kinds of literature had justified the remarkable significance of the green building developments to the design of advanced and efficient integrated energy technologies to reduce electricity, loads such as heating, cooling, etc. in the form of energy demand and the consumptions through the on-site RE sources approach [41], [42]. Since utilizing RE as one of the most key elements of green buildings [43], this significantly increases the integration of PV-based DG (PV-DG) to the highest possible capacity into power system network prior to given maximum scoring of respective GBRS [44] and even exceeding the RE maximum scoring in GBRS.

Obviously, the outcome of the above study which was summarized in Tables 1 - 3 had portrayed the small imposed for RE capacity from the current seven different GBRS. Therefore, the two previously mentioned recent policies by MESTECC, i.e. to encourage the green building development for at least 20% by 2020 [17] and to enlarge the green and efficient energy sector by increasing the percentage of RE from 2% towards 20% for electricity generation by 2025 [21]–[23], can possibly result in the change of RE landscape in green building current practice and also will lead towards evolution for extreme expansion scale in RE utilization beyond the current GBRS base case in assessment criteria. From a green building development perspective, the drastic increment of RE quota by 18% from the original target will significantly overlap the RE development, which will subsequently increase the current imposed of utilization such as PV-DG integration beyond the current RE setting in GBRS application. The only scheme that allows for higher capacity than

| GBRS    | Intent / Aim of RE Application                                                                                                                                 |
|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MyCREST | To provide/maintain the generation of electricity from renewable resources and reducing the effect on environment pollution by reducing greenhouse gas emissions.       |
| GBI     | Encourage the use of RE.                                                                                                                                         |
| GreenRE | Encourage the application of RE sources in buildings.                                                                                                         |
| Green Ship | Not stated.                                                                                                                                                  |
| Green Mark | On-site generation of RE can reduce the building development’s power consumption from the grid and carbon emissions.                                    |
| TREES   | Give priority to use RE to reduce environmental and social impacts associated with fossil fuel energy use.                                                   |
| LEED v4 | To encourage the reduction of greenhouse gas emissions through the use of local and grid-source RE technologies and carbon mitigation projects.             |

Therefore, the two previously mentioned recent policies by MESTECC, i.e. to encourage the green building development for at least 20% by 2020 [17] and to enlarge the green and efficient energy sector by increasing the percentage of RE from 2% towards 20% for electricity generation by 2025 [21]–[23], can possibly result in the change of RE landscape in green building current practice and also will lead towards evolution for extreme expansion scale in RE utilization beyond the current GBRS base case in assessment criteria. From a green building development perspective, the drastic increment of RE quota by 18% from the original target will significantly overlap the RE development, which will subsequently increase the current imposed of utilization such as PV-DG integration beyond the current RE setting in GBRS application. The only scheme that allows for higher capacity than
**TABLE 2.** The RE criteria setting and scoring (credit) among selected GBRS.

| GBRS      | Scoring Credit | RE Criteria Setting                                      |
|-----------|----------------|----------------------------------------------------------|
| MyCREST   | 4 (max) 3% from Total Building Energy Use                 |
|           | 3 (min) 2% from Total Building Energy Use                  |
|           | 2 (min) 1% from Total Building Energy Use                   |
|            | 1 (min) 0.5% from Total Building Energy Use                 |
| GBI       | 5 (max) 2% of MD or 40 kWp (which is greater)               |
|           | 4 (max) 2% of MD or 20 kWp (which is greater)               |
|           | 3 (max) 1.5% of MD or 10 kWp (which is greater)             |
|           | 2 (max) 1% of MD or 5 kWp (which is greater)                |
|           | 1 (min) 0.25% of MD or 2 kWp (which is greater)             |
| GreenRE   | 15 (max) 3% via of electricity by RE source                 |
|           | 10 (max) 2% via of electricity by RE source                 |
|           | 5 (min) 1% via of electricity by RE source                  |
| Green Ship| 5 (max) 2.0% of MD or 40 kWp (which is greater)             |
|           | 4 (max) 1.5% of MD or 20 kWp (which is greater)             |
|           | 3 (max) 1.0% of MD or 10 kWp (which is greater)             |
|           | 2 (max) 0.5% of MD or 5 kWp (which is greater)              |
|           | 1 (min) 0.25% of MD or 2 kWp (which is greater)             |
| (For EEI >120) | Replace of building electricity by 3% RE                  |
| Green Mark| 6 (max) Replace of building electricity by 2.5% RE         |
|           | 5 (max) Replace of building electricity by 2.0% RE         |
|           | 4 (max) Replace of building electricity by 1.5% RE         |
|           | 2 (max) Replace of building electricity by 1.0% RE         |
|           | 1 (min) Replace of building electricity by 0.5% RE         |
| TREES     | 4 (max) RE not less than 3.5% of energy cost                |
|           | 3 (max) RE not less than 2.5% of energy cost                |
|           | 2 (max) RE not less than 1.5% of energy cost                |
|           | 1 (min) RE not less than 0.5% of energy cost                |
| LEED v4   | Points = \( \frac{RE \text{ generated} \%}{1.5\%} \) + \( \frac{Energy \text{ purchased or offset} \%}{25\%} \) |
|           | Maximum, RE capacity = 1.5% of total building energy use   |

**TABLE 3.** The group for highest RE capacity among selected GBRS.

| GBRS         | Max PV-DG percentage from MD prior to the highest scoring |
|--------------|----------------------------------------------------------|
| MyCREST      | 3%                                                       |
| GreenRE      | 2.0% or 40 kWp (whichever greater)                        |
| Green Mark   | 1.5%                                                      |
| GBI          | 1.5%                                                      |
| Green Ship   | 1.5%                                                      |
| LEED         | 1.5%                                                      |

**FIGURE 1.** A complete PV-DG system and parameters for a measure in which the AC output components through the distribution network were still falling within the boundary of the complete PV system.

Any GBRS current setting for PV-DG building integration in Malaysia is Net Energy Metering (NEM) which applies to all domestic, commercial and industrial sectors [45]. However, the simulated PV-DG expanded capacity through NEM maximum capacity requirement via an optimization approach, as conducted in [33] using three selected Malaysian public hospitals’ distribution networks and bus data has highlighted several issues. MATLAB simulation results for higher PV-DG scale have found that the performance yield for load and loss minimization tend to decrease upon larger utilization of PV-DG scale towards optimal value via the current linear trend for PV-DG increased capacity. This significantly causing the actual useful energy consumption for load and loss minimization to become increasingly underutilized upon the increase of PV-DG capacity and potentially prolong the payback period for CAPEX and OPEX through theoretical calculation.

In extend, the RE system performance decreases due to line losses, and due to variation of voltage level, thus the selection for location and capacity of DG sources are found to be more important in dependably on the system losses and voltage stability measure as compared with several others objective function settings [46]. With regards to the previously-mentioned losses issue in a distribution network and considering the required appropriate measure in RE application in green building as previously mentioned by Amir et al. [39], the useful RE consumption yield issue as above have highlighted a gap for assessment towards higher performance measure in RE installation. In contrast, simultaneous optimization criteria for PV-DG location and capacity are still lacking in applying appropriate performance indices into current selected GBRS assessment criteria for more justified value towards both minimal losses and payback period worth.

**B. INDICES FOR PV-DG PERFORMANCE**

Based on IEC 61724, a complete PV-DG system with different parameters to be measured in real-time is shown in Fig. 1 [47].

Referring to Fig. 1 and focusing on the flow of the voltage \( V_L \) and current \( I_L \) towards load consumption, the AC output components through the distribution network were still falling within the boundary of the complete PV system, where these parameters shall be considered in the calculation for the whole PV-DG performance measure. Since loss contribution in the grid-connected distribution with high R/X ratio which consists of large varieties of components like thermostatic loads, resistive and inductive loads, induction motors, and lighting loads [48], [49] added with factors of
characteristics in distribution network and load demand levels as accordance to Van Thong et al. [50], the value of useful power $P_L$ would be possibly affected, caused by the existence of bi-directional power flow from utility and the PV-DG. Thus, the scenario has introduced a gap to obtain optimal line loss and the useful power yield for higher PV-DG performance measures specifically on the AC distribution side.

Initially, there are several parameters to judge the performance of a PV-DG plant, where [51] had highlighted several of them such as specific yield, capacity utilization factor (CUF), performance ratio (PR), performance index (PI), etc. PR shows the proportion of the energy that is available for export to the grid after the deduction of energy loss (e.g. due to thermal losses and conduction losses) and energy consumption for operation [52]. PR also has been reported as the ratio of final system yield ($Y_f$) to that of reference yield ($Y_r$) as shown in (1) as accordance to IEC standard [53], National Renewable Energy Laboratory (NREL) [54], International Energy Agency Photovoltaic Power Systems (IEA PVPS) Task 2 [55], European Guidelines, and Australian PV System Monitoring Guideline [56].

$$\text{Performance Ratio(\text{PR})} = \frac{Y_f}{Y_r} \quad \text{(1)}$$

Various definition of $Y_f$ and $Y_r$, as well as PR formulation have been reviewed by Khalid et al. [51] where ten references of them were presented by Haeberlin and Beutler [57]; IEC 61724 Methodology [53]; IEA PVPS TASK 2 Methodology and NREL/CP-520-37358 Performance Parameters for Grid-Connected PV Systems [54]; EU Performance Monitoring Guideline for Photovoltaic Methodology - PERFORMANCE Project; Kymakis et al. [58]; SMA Methodology via Kymakis et al. [58]; Ransome et al. [59]; PR-FACT Mack and Decker GmbH In-house Methodology; and Australian PV System Monitoring Guideline Version 1.0 [56]. Besides, the above-selected references had been claimed to be represented as one of the most cited works in the literature on PR for PV plants and are also a perfect mix for global understanding. This also justifies the reason behind the selection of these various sources to portray the PR definition which is summarized in Table 4. However, none of them has considered the line loss contribution in the formulation which translated by the useful consumption yield as it was identified as essential to the AC distribution side as discussed above.

Based on Table 4, it is observed that four out of the ten references (i.e. IEA PVPS TASK 2 Methodology – 2001; NREL/CP-520-37358 report [54]; EU PERFORMANCE Project and Australian PV System Monitoring Guideline [56]) are applying the standard equation used by IEC 61724 to define the PR. Whereby, three references by Haeberlin and Beutler [57]; Kymakis et al. [58] and Ransome et al. [59] have presented the PR in two ways: one, as defined by IEC 61724 and second, a new definition using correction factors, inefficiencies, and uncertainty functions respectively. PR-FACT Mack and Decker GmbH methodology have defined PR using different correction factors. SMA has defined the PR in terms of the actual reading of the plant output and nominal output of the plant.

Focusing on the grid or distribution network for PV-DG performances, only two references, i.e. Kymakis et al. [58] and PR-FACT Mack and Decker GmbH had highlighted the availability and grid connection loss represented by a factor of $\eta_{pve}$ and $f_{10}$ respectively. The rest of the references might include the distribution losses factor in the calculation, however, the detail formulation and input parameter of these factors in terms of line losses and load consumption had identified a gap, which needs to be strengthened by the evidence-based input ratio towards the optimal approach. In addition, the impact of this factor in terms of the payback period milestone would also highlight the importance of optimal losses and the useful energy consumption yield for load and loss minimization to be considered in the formulation. Therefore, the proposed input parameter and the ratio of related fields on behalf of $Y_f$ would give access for improved PR towards the extended version for a more accurate figure and is explained in later discussion.

Responding to the performance measure needs and subjected to PV-DG grid-connected application, PR which is recognized as a globally accepted indicator to measure the overall performance of the system [51], however, the ratio of useful energy consumption which revealed via the PV-DG optimization towards minimal losses outcome has not yet been factored in the PR formulation. Thus, leaving a gap towards PR viability for improved figure, considering an optimal PV-DG outcome towards minimal losses as a key factor as this would determine the limit of PV-DG expansion and the payback period worth for the CAPEX and OPEX.

C. THE PAYBACK PERIOD ASSESSMENT

The definition of payback period can be referred to as the required length of years or time consumed in recovering the initial/original investment. The shorter payback period is considered as a better indication project provided that all constant factors took in place since invested capital can be recovered in a shorter period [60]. The payback is also used as a risk indicator for a project since the expected cash flow in a lengthy timeline is riskier than a shorter timeline which also determines the projected liquidity [61].

Concerning the PV-DG energy generation, Hoffmann [62] defined the energy payback time as a period for the required amount of energy to be produced by a PV module. Therefore, it is also an environment parameter that needs to be taken care of. While the time is dependent on the cumulated insolation where a longer energy payback items at larger geographical latitudes, an absolute value comparison requires a crystal-clear definition for the energy consumptions that are to be taken into account to manufacture the solar module. Several studies have been conducted on the feasibility of implementing PV-DG systems in different countries. Wijesuriya et al. [63] introduced the concept of fixing several reflectors near the panel reflecting sunlight from outside the panel area onto the panel, increasing the energy output.
The objective is to place the reflectors so that they never throw their shadows on the panel or on other reflectors where this approach can increase the resource utilization, especially during the periods where the inception angle significantly deviates from the optimal right angle. A cost-benefit analysis was implemented to decide if the investment would be financially feasible. The analysis comprised calculating the net present values of the annual cash flows along with the calculation of the payback period. The outcomes of the cost-benefit analysis turned out to be positive reducing the overall payback period from 22 years to 18 years by enhancing output generated power via efficient reflectors setting.

Bakos et al. [64] applied computerized renewable energy technologies (RET) to obtain a BIPV grid-connected feasibility analysis. A BIPV with 2.25 kWp capacity consists of 3 sinusoidal inverters (850 W nominal power of each). The energy production amount and the cost of the system were estimated to be 4,000 kWh/year and $24,000 respectively. The payback period was found between 20 and 50.1 years for different subsidy amounts ranging between 0% and 60%.

### TABLE 4. PR formulation from various sources.

| Sources                                                                 | PR Formula                                                                                           | Abbreviations                                                                                     |
|------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| Haeberlin and Beutler [57]                                             | \[ PR = \frac{Y_r}{Y_f} = K_T \times K_g \times n_i \]                                               |                                                                                                   |
| IEC 61724 [53]                                                         |                                                                                                      |                                                                                                   |
| IEA PVPS TASK 2 [54]                                                   | \[ PR = \frac{Y_f}{Y_r} \]                                                                          |                                                                                                   |
| NREL/CP-520-37358 [54]                                                 |                                                                                                      |                                                                                                   |
| EU PERFORMANCE Project                                                 |                                                                                                      |                                                                                                   |
| Australian PV System Monitoring Guideline [56]                         |                                                                                                      |                                                                                                   |
| Kymakis et al. [58]                                                    | \[ R_p = \eta_{deg} \times \eta_{temp} \times \eta_{soil} \times \eta_{loss} \times \eta_{watt} \times \eta_{loss} \times \eta_{ppe} \] |                                                                                                   |
| SMA Methodology [58]                                                   | \[ PR = \frac{Actual\ reading\ of\ plant\ output\ in\ KWh\ p.a.}{Nominal\ plant\ output\ in\ KWh\ p.a.} \] |                                                                                                   |
| Ransome et al. [59]                                                    | \[ kW_{AC} = kW_{AC,optimal} \times \frac{insolation\ yearly}{insolation\ nominal} \times \frac{f_{downtime}}{f_{degradation}} \times \frac{f_{dirt}}{f_{seasonal}} \times \frac{f_{shading}}{f_{BOS}} \] |                                                                                                   |
| PR-FACT Mack and Decker GmbH                                           | \[ PR = f_0 \times f_1 \times f_2 \times \ldots \times f_{10} \]                                      |                                                                                                   |

| Abbreviations                                                                 |                                                                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------|
| \( K_T \) - Temperature correction factor, \( K_g \) - Generation correction factor, \( n_i \) - Inverter efficiency        |
| \( R_p \) - PR                                                                                                                    |
| \( Y_r \) - final yield, \( Y_f \) - final yield, \( \eta_{deg} \) - panel degradation loss, \( \eta_{temp} \) - temp loss, \( \eta_{soil} \) - soiling loss, \( \eta_{loss} \) - DC wiring and interconnection loss, \( \eta_{watt} \) - inverter loss, \( \eta_{loss} \) - transformer loss, \( \eta_{ppe} \) - availability and grid connection loss of the PV plant |
| \( p.a. \) - per annum                                                                                                           |
| \( kW_{AC} \) - AC output                                                                                                        |
| \( f \) - uncertainty function due to downtime, panel degradation, soiling, seasonal change, shading, the balance of system effects, reference module calibration, flash effect, module binning and manufacturer declaration of the PV plant |
Peng et al. [65] conducted a cooling test on solar PV system for efficiency improvement via cooling condition which achieved an increasing rate of 47% and was proposed for possible system setup of residential solar PV application. The cost payback time uses CUF and direct multiplication with the utility tariff rate which can be reduced to 12.1 years, compared to 15 years of the baseline of a similar system without a cooling sub-system.

Chang and Starcher [66] evaluated the benefits of wind and solar energy and determine economical investment sites for wind and solar energy in Panhandle Texas through calculating payback periods based on quantified actual electricity generation. An AOC 15/50 50kW wind turbine system and a 42 kW PV system at the Alternative Energy Institute (AEI) Wind Test Centre (WTC) were used to collect field data. The payback period was calculated based on energy production, the cost of electricity, and incentives and rebates available for the project. The payback period of the PV system was calculated based on the energy production estimates. The PVWATTS Calculator estimated the energy production of the two-tracker array system. It determined the solar radiation incident on the PV array and the PV cell temperature for each hour of the year using typical meteorological weather data for the selected location. The DC energy for each hour was calculated from the PV system DC rating and the incident solar radiation and then corrected for the PV cell temperature. The AC energy for each hour was calculated by multiplying the DC energy by the overall DC-to-AC conservative derating factor equal to 0.9 and adjusted for inverter efficiency as a function of load. Hourly values of AC energy were then summed to calculate monthly and annual AC energy production.

Seme et al. [67] presented a multi-criteria evaluation analysis of the optimal price of electricity of Solar Power Plants (SPP) and Small Hydro Power Plants (SHP). The objective of this paper is to deal with the technical and economical part of the investment in the construction of a solar power plant and a small hydropower plant. The basis of the investment and operating costs analysis of the viability of investment at different purchase prices of electricity is implemented, with the help of acceptance indicators. The calculation of the payback period was performed for the reference price of electricity and for the price of electricity by which the investment is repaid in 10 years for both SPP and SHPP. The results show that the payback period for the reference price for SPP and SHPP was 30.8 and 18.2 years. This paper also found that the purchase price of electricity for SPP was 2 to 3 times higher than the purchase price of electricity for SHPP.

Numbi and Malinga [68] presented an optimal energy control of a 3kW residential grid-interactive solar PV system is presented. They proposed true payback period method for the analysis of the residential grid-interactive solar PV system in this work. In this study, the annual costs are the O&M costs and annual cost savings as in equation uses direct multiplication between tariff rate and PV output generated power.

Thompson and Duggirala [69] had presented a feasibility study and a cost analysis of renewable energies at a small off-grid facility in Canada where the electricity was supplied to the studied building mainly by diesel engines using natural gas as a fuel. The economic and environmental feasibility of three different scenarios to replace the current 100 kW diesel engine by one of the following new technologies, i.e., biomass combined heat and power, wind energy and PV system were studied and were made comparable using a developed RETScreen software model-based. They concluded that the PV system at $9,100/kW is the most expensive among the technologies, requiring a long payback period of 13.5 years. Whereas compared with installing a new diesel generator or implementing a biomass system, wind power was found to be more expensive at $3,300/kW with 6.1 years payback period. Thus, biomass combined energy is more economically and environmentally feasible than wind or PV technologies with the lowest payback period of about 4.1 years. It is also found that the payback period calculation had considered the PV efficiency of 12.3%. However, line loss contribution was not taken into account.

Mirzahosseini and Taheri [70] investigated three scenarios of alternative energy solution for Iran, in terms of the financial feasibility and environmental aspect of using a PV solar power station via RETScreen. They examined the electricity price rate at 3.74 cents/kWh, making the equity payback period significantly higher at about 12.1 years as the first scenario. Then, the second scenario was to increase the electricity tariffs to 17.5 cents/kWh, resulting in the equity payback period decreased to 8 years. Finally, in making use of an incentive benefit of $30 for each ton of CO₂ removal, they considered the issue of GHG reduction, which results with decreasing in the equity payback period to 6 years. However, it was found that this investigation does not consider PV efficiency and line loss contribution in the payback period calculation.

Bakos and Soursos [71] dealt with a stand-alone PV and a hybrid system for a technical and economical evaluation for lowering the electricity prices at resorts in Greece. Simulation using the software in renewable energy technologies, economic issues were examined via three different payment schemes scenarios specifically on the percentage of the initial capital cost. Without consideration of PV efficiency and line loss contribution, the payback period and net present value (NPV) for several financial scenarios are predicted to gain the gross returns on the investment.

Dusonchet and Telaretti [72] conducted a survey for five representative EU countries, i.e., Germany, the UK, France, Italy, and Greece in terms of the economic indices, best profitability, NPV and the payback period for PV systems towards varying size for backup policies evaluation for PV systems for comparative economic analysis. This survey has resulted in an indication of the achievable of the best profitability for
these countries due to an active compensation scheme despite the high cost of electricity.

Adam and Apaydin [73] applied RETScreen software for financial analysis and determination of the GHG eliminated by using a PV system to perform an estimated reduction volume for the carbon dioxide emission via PV system (grid-connected) in Gaziantep, Turkey, instead of using a barrel of petroleum. In this study, the proposed case of power system uses electricity exported to the grid which equivalent to 881.5 MWh, while PV capacity of 500 kWp with a capacity factor of 20.1%. The efficiency or ratio of line losses is not considered. The result represented by the cumulative cash flow graph showed that the 3.2 years is the achievable equity payback period, plus with the advantage that the PV system being free of GHG. On top of that, the authors suggested that legislation to promote the use of PV systems and increase electricity tariffs should be enacted by the government.

Rehman et al. [74] using RETScreen software for the cost of solar energy generated study via 5 MWp grid-connected PV panels in Saudi Arabia. The model calculates the annual renewable energy delivered (MWh), which is the amount of equivalent DC electrical energy delivered by the PV system to the load, or the utility in the case of the grid-connected system. The maximum annual energy production of 12.4 GWh was obtained from Bishah power plant (with power plant efficiencies of 28.3%) while the minimum of 8.2 GWh from Tabuk and Sarrar power plants (with power plant efficiencies of 18.7%). From the payback period calculation, NPV, profitability index, and life cycle savings, the economic analysis revealed that Bisha is the best location for a PV power plant where the results showed that 8182 tons of GHG per year can be eliminated due to establishment of such a plant.

Crawford et al. [75], identified the payback period through life cycle assessment from two different types of combination PV cells-heat recovery unit. Two 75 W Si PV modules with a total area of 1.26 m² were used as the first system, next, a heat recovery unit was added in the second system to benefit from the wasted heat produced by the PV modules. In the third system, a-Si PV modules were used instead of c-Si PV modules. The result of the energy payback period for the first system was found to be between 12 and 16.5 years. Whereas the second system achieved between 4 and 9 years and finally the third system between 6 and 14 years.

Chel et al. [76] applied a methodology to an actual case study of 2.32 kWp PV system for life cycle cost assessment and sizing of BIPV systems through a simplified model. Two defined sub arrays comprised of 32 PV modules (35 Wp each) and 16 PV modules (75 Wp each) respectively, whereas, the capital cost for the BIPV system was $6,963/kWp. In addition, the unit cost of electricity from BIPV was estimated to be $0.46/kWh. However, when the carbon credit potential of the system was considered, the unit cost decreased to $0.37/kWh. The calculated payback period was equivalent to 10 years considering total annual energy generated by the system equal to 3,285 kWh.

San Ong and Thum [61] had determined the net present value (NPV), the total cost, price/kWp system, and the payback period for PV projects in Malaysia. The selected 7 projects, i.e. Project 1 to 7 have been used in the analysis where the findings of all 7 projects had shown a negative NPV value with a payback period of more than 38 years. The analysis also found that 4 projects even achieving a payback period of more than 50 years. However, a positive NPV is possibly achieved if the price/kWp system managed to be reduced to RM11,000 and RM4,000 for government-subsidized and non-subsidized projects respectively. The estimation on the payback period was achievable between 4 and 8 years with a current market price reduction of between 85% and 50% respectively.

Hou et al. [77] analyzed the life cycle inventory during every process were estimated in detail followed by the energy consumption and greenhouse gas (GHG) emission and the life-cycle value was calculated accordingly. The results for the grid-connected PV power showed that the crystalline silicon solar modules resulting in ranges from 1.6 to 2.3 years for the energy payback time (EPBT). Depending on the installation methods, GHG emissions, on the other hand, resulted in a range from 60.1 to 87.3g-CO₂eq/kWh.

Rodrigues et al. [78] had overcome with analysis to identify the best investment opportunities via considering the new regulations among a representative set of countries, including Australia, Brazil, China, Germany, India, Iran, Italy, Japan, Portugal, South Africa, Spain, the UK and the USA. Furthermore, 2 case studies were employed with different sizes of solar photovoltaic systems, i.e. 1 kW and 5 kW where each case study includes 4 different consumption scenarios ranging from 100% self-consumption to 30%. The results found that Australia, Germany, and Italy had shown the most profit that can be made in.

Wang et al. [79] investigated the first standalone hybrid renewable energy commercial microgrid in Hong Kong via a life cycle assessment (LCA) case study of the Town Island Microgrid for the life cycle environmental impacts and the energy payback time (EPBT). Furthermore, 2 electrification options, including a non-site diesel generator system and a grid extension was tested for the environmental performance of the Town Island Microgrid. The EPBT result has resulted in 9.2 years for the microgrid, while the grid extension and the diesel generator EPBT values were 6.4 and 10.1 times longer than that of the microgrid, respectively.

Fan and Xia [80] have presented a building envelope retrofitting via a multi-objective optimization model to select the best use of financial investment for maximizing the energy savings and economic benefits. The main performance indicators for the retrofitting plan have taken the NPV, the payback period and energy savings in the multi-objective optimization problem formulation as a non-linear integer programming problem and solved by a weighted sum method.

Following the above recent study related to payback period assessment, the identified applied formulation that can be
TABLE 5. The payback period formulation from various sources.

| Sources | Payback Period Formulation |
|---------|----------------------------|
| Chang and Starcher [66] | $P = \frac{I_c - I_n}{A_E \times P_e - AOM}$ |
| Abbreviations: | |
| $I_c$ = Initial cost of installation. | |
| $I_n$ = Value of the national or state incentives. | |
| $A_E$ = Annual energy production. | |
| $P_e$ = Rate of electricity. | |
| $AOM$ = Annual operation and maintenance cost. | |
| True Payback Period = $\frac{PW_{TC}}{PW_{TB-av}}$ | |
| $PW_{TB-av}$ is the annual average $PW_{TB}$ obtained using equation as below; | |
| Numbi and Malinga [68] | $PW_{TB-av} = \frac{PW_{TB}}{n}$ |
| Abbreviations: | |
| $PW_{TC}$ = Present worth (PW) of total costs | |
| $n$ = Project lifetime | |
| $PW_{TB}$ = PW of total benefits i.e. which are the annual cost savings less any annual costs discounted to a PW and incurred by the user during operation. | |
| Chel et al. [76] | Payback period = $\frac{\text{Embodied energy (kWh)}}{\text{PV Energy generated (kWh/year)}}$ |
| San Ong and Thum [61] | Payback period = Year before full recovery + $\frac{\text{Unrecovered cost at start of year}}{\text{Cash flow during year}}$ |
| Rodrigues et al. [78] | Simple Payback period (SPBP) = $\frac{\text{Initial Investment (€)}}{\text{Annual Saving (€/year)}}$ |
| Fan and Xia [80] | $T_p = N + \frac{C_{fn}}{C_{tn}}$ |
| Abbreviations: | |
| $N$ = the last month with a negative cumulative cash flow, | |
| $C_{fn}$ = the absolute value of the cumulative cash flow at the end of the N-th month ($)$, | |
| $C_{tn}$ = the total cash flow during the (N + 1)-th month ($)$ | |
| Hou et al. [77] | Energy Payback Time ($T_{EBT}$) = $\frac{\text{Total Consumed Energy}}{\text{Annual Output Energy}}$ |
| Wang et al. [79] | $EPBT$ year = $\frac{\text{Total Primary Energy Demand}}{\text{Annual Energy Output}}$ |

Critical Evaluation:
The utilization of adjusted factor towards consideration of specific potential line losses and low performance is not considered in the overall formulation.

extracted within several of these references is highlighted in Table 5. To summarize, the above formulations (Table 5) for early estimation purposes do not highlight the utilization of
adjusted factors towards consideration of specific potential line losses and low performance to obtain a more accurate total energy generated figure. The grid condition in deeper insight for total line loss and higher performance have not been discovered yet specifically towards the impact on the payback period calculation. This is important since simultaneous optimization criteria for RE-based DG location and capacity was found to be more effective to be observed via minimal losses outcome [34] and also implemented in many recent kinds of literature [33]–[37], therefore, this has shown a gap for measuring the factor which comprised of line losses outcome and higher performance indicator followed by the payback period assessment to validate its’ potential as previously-briefed.

D. RESEARCH GAP AND CONTRIBUTION OF STUDY

The overall review from the literature had overcome the research gap which focuses on measuring the line losses outcome for improving initial estimation in payback period calculation and introducing ratio of useful consumption yield for load and line loss minimization as part of the input parameter of $Y_f$ in PR formulation.

Thus, the proposed assessment of PV-DG performance offer a new contribution of knowledge as well as justification on the importance of the study which is portrayed in-depth towards achieving a more sensible and transparency outcome especially in the payback period value. This also will encourage the developers, building owners, and users, in participating in achieving potential benefits both in monetary and power system reliability improvement. The contributions of this paper can be summarized as follows:

- Introduce and highlight the existence of the ratio $\phi$ of useful energy consumption for load and loss minimization from the PV-DG generation and proven its potential in determining the end-result of payback period outcome via proposed assessment.
- Introduced an adjusted factor in obtaining accurate total energy generated in payback period measurement.
- Highlights in-depth explanatory of $\phi$ which contributes towards the determination of useful energy consumption yield from the PV-DG generated power.
- The desired performance level for PV-DG can be tuned via a downstream-to-upstream approach considering the desired payback period as an initial basis for the upstream parameter.

In specific, this paper introduces a potential factor in the final yield ($Y_f'$) input parameter which significantly improves the PR towards extended version for a more accurate figure.

III. RESEARCH METHOD

The extensiveness of the PR as the overall PV-DG performance indicator is being improvised towards extended version by introducing the ratio $\phi$ of useful energy consumption for load and loss minimization from the PV-DG generation which includes total line loss minimization outcome as part of an input parameter. This factor is proposed to be considered in PR formulation as an indicator to translate on how well the PV-DG generated power is being transferred along with the AC distribution network for load consumption and loss minimization which also determining the overall performance of PV-DG installation. This also significantly justifies the PV-DG expansion-limit and contributing to the final yield ($Y_f'$) input parameter towards the upper level of accuracy.

The assessment for measuring both PV-DG performance and payback period uses a simulated based-outcome of PV-DG expanding baseline from a previous work by [33] which focused on three selected Malaysian public hospitals’ distribution network. The research boundary for this study is illustrated with orange color in Fig. 2.

The overall flow of this study as illustrated in Fig. 3. All processes are examined for the National level, State level, and...
District level hospital according to the previous application for PV-DG expansion-limit assessment. In the first process, a review on the various PR and payback period formulation is performed to identify their significance on the input data which could project a more transparency in both system performance and payback outcome. Then, the preliminary input data is gained from the previous work as discussed above. Consequently, the PR ratio is calculated and the $\phi$ and $P_{\text{Load}}$ are obtained, and finally, the payback period assessment is performed to validate the potential outcome of the proposed factor.

A. PERFORMANCE MEASURE CONSIDERING PV-DG EXPANSION NEEDS IN GBRS

In this part, the simulation result in [33] is used as the input parameter which comprised of the values as follow:

- The maximum demand (MD) for the three selected distribution networks (National-level hospital (Zone A only), State-level hospital (Zone A only) and district-level hospital (Zone A)).
- The total power supply by substation ($P_{\text{base}}$) and MD ($P_{\text{Load}}$) data.
- PV-DG expanding capacity from 15% of MD through 5% ascending stages up to an optimal point.
- PV-DG expansion-limit and the optimal value.
- Total line loss ($TLL$) value for all PV-DG values up to the optimal point (expansion-limit).

The detail of the input data for the above parameter is shown in Table 6. This previous work has portrayed the real findings for practical application which also highlights the uniqueness of the solution towards an effective PV-DG outcome for selected public hospitals as compared to other types of buildings. The PV-DG optimization for capacity and location simultaneously has demonstrated a stochastic approach throughout a 50 random search via the Artificial Bee Colony (ABC) algorithm and has partially solved the way forward for PV-DG expansion capacity via NEM scheme in selected public hospitals to a certain limit of effectiveness. This limit provides a beneficial information to the RE developer in obtaining the best option for expanding PV-DG installation via a NEM scheme as well as providing the lowest power loss impact on the existing network. Therefore, the information has an advantage and very useful for practical application.

The input parameter for simulated outcome must fulfill all constraints while striving the main objective to reduce the power losses. This important procedure needs to be observed during the assessment process to ensure violation of any limit is not occur in the solution. Assessment process with all constraints for unlimited and limited capacity as listed below:

a) Power balance constraint [81]–[83];

$$P_{\text{DG}} + P_{\text{base}} = P_{\text{Load}} + TLL \quad (2)$$

where the summation of the total power supply by substation and power output from the DG must be equal to the total size of load plus total power losses.

b) The ratio of useful energy consumption for load and loss minimization from the PV-DG generation (%);

To highlight the loss level dependency on penetration, dispersion level, type of DG technology, distribution network characteristics and load demand levels as highlighted by Van Van Thong et al. [50], a $\phi$ measure of useful consumption for load and loss minimization by the PV-DG generation is being derived where (2) is referred as the basis of the ratio formulation setup. Then, considering the measurement of an output value by input value, the ratio $\phi$ can be obtained by (3);

$$\phi = \frac{P_{\text{Load}} + TLL}{P_{\text{Base}} + P_{\text{DG}}} \quad (3)$$

Thus, $\phi$ for solving the power transfer performance of $P_{\text{DG}}$ for line loss minimization in the radial distribution network is made using (3) for all cases of study and is graphically plotted to highlight the actual power consumption curve towards total line losses minimization, and the output curve is expected to be in a non-linear form.

| Network location | National-level hospital | State-level hospital | District-level hospital |
|------------------|------------------------|---------------------|------------------------|
| $P_{\text{Load}}$ (kW) | 1097 | 1248 | 1232 |
| $P_{\text{Base}}$ (kW) | 1561 | 1598 | 1880 |
| PV-DG size (kWp) & limit/ optimal | 165 (15% of MD) | 187 (15% of MD) | 246 (20% of MD) |
| 219 (20% of MD) | 250 (20% of MD) | 308 (25% of MD) |
| 274 (25% of MD) | 312 (25% of MD) | 370 (30% of MD) |
| 329 (30% of MD) | 374 (30% of MD) | 431 (35% of MD) |
| 384 (35% of MD) | 437 (35% of MD) | 493 (40% of MD) |
| 439 (40% of MD) | 499 (40% of MD) | 554 (45% of MD) |
| 494 (45% of MD) | 562 (45% of MD) | 616 (50% of MD) |
| 546 (limit/ optimal) | 624 (50% of MD) | 678 (55% of MD) |
| 654 (limit/ optimal) | 739 (60% of MD) | 793 (65% of MD) |
| 801 (65% of MD) | 862 (70% of MD) | 885 (limit/ optimal) |
| Initial Loss, $L_1$ (kW) | 464 | 350 | 648 |
| Total | 201 | 113 | 193 |
| Loss, $L_2$ (kW) | 136 | 89 | 62 |
| 89 | 62 | 60 |
FIGURE 4. The $\phi$ outcome for National-level hospital (Zone A).

FIGURE 5. The $\phi$ outcome for State-level hospital (Zone A).

FIGURE 6. The $\phi$ outcome for District-level hospital.

B. PAYBACK PERIOD ASSESSMENT, COMPARISON AND EXPECTED MINIMIZATION

The advantages of the PV-DG expansion-limit via optimal losses with higher useful consumption yield are measure towards the payback period impact outcome for CAPEX and OPEX. As such, the assessment for this payback period is highlighted by selecting the most optimal PV-DG capacity including its total line
TABLE 7. Estimated CAPEX.

| No. | Description                                      | Value       |
|-----|--------------------------------------------------|-------------|
| 1   | Preliminaries                                    | 1% (RM50.00)|
| 2   | Solar Panel                                      | 45% (RM2,250)|
| 3   | Inverter & Cable                                 | 36% (RM1,800)|
| 4   | Mounting Structure                               | 9% (RM450) |
| 5   | DC & AC Switchboard                              | 7% (RM350) |
| 6   | Earthing System                                  | 2% (RM100) |
|     | **Estimated CAPEX**                              | **RM5,000 per kW** |

TABLE 8. Estimated OPEX.

| No. | Description                                      | Value   |
|-----|--------------------------------------------------|---------|
| 1   | Projected OPEX for year 1 (RM)                   | CAPEX x 1% |
| 2   | Projected OPEX for consecutive years (%)         | 3% per year |
| 3   | Major replacement every 10 years (inverter and cables) | Estimated CAPEX x 36% |

TABLE 7. Estimated CAPEX.

Three sets of payback period assessment worksheet, i.e. $PP_1$, $PP_2$, and $PP_3$, were established which represent all level hospitals, i.e. for National, State, and District-level hospital respectively as according to the simulation result as previous-discussed where these also involved in examining the role of the ratio $\varphi$ towards measuring the payback period implication.

The CAPEX and OPEX for this research adopt the estimated-based values from the database [84] as well as several referral projects related to the PV-DG system implemented by MoH. The rest of the calculation that relates to payback period calculation constitutes estimated CAPEX (Table 7), estimated OPEX (Table 8) and input parameter in payback period calculation (Table 9).

TABLE 9. Basic input parameter in payback period calculation.

| No. | Description                                      | Value   |
|-----|--------------------------------------------------|---------|
| 1   | Estimated PV-DG capacity (kW)                    | $P_{DG}$ |
| 2   | Active power of slack bus (kW)                   | $P_{Max}$ |
| 3   | Initial line losses – without PV-DG connection (kW) | $L_1$ |
| 4   | Total line losses simulated outcome with PV-DG connection (kW) | $L_2$ |
| 5   | The ratio of useful energy consumption for load and loss minimization from the PV-DG generation (%) | $\varphi = \frac{P_{Load} + L_1}{P_{Max} + P_{DG}}$ |
| 6   | The useful energy consumption yield for load and loss minimization (kW) | $P_{Actual} = P_{DG} \times \varphi$ |

TABLE 10. Table of results for National-level hospital.

| Case | (PV-DG % from MD) | 1 | 2 (15) | 3 (20) | 4 (25) | 5 (30) | 6 (35) | 7 (40) | 8 (45) | 9 (Optimal) | 10 (50) | 11 (55) | 12 (60) | 13 (65) | 14 (70) | 15 (75) |
|------|-------------------|---|--------|--------|--------|--------|--------|--------|--------|------------|--------|--------|--------|--------|--------|--------|
| ZONE A | 1097 (kW) | Optimal | PV-DG in kW | 165 (bus 5) | 219 (bus 7) | 274 (bus 4) | 329 (bus 7) | 384 (bus 4) | 439 (bus 7) | 494 (bus 4) | 546 (bus 7) | 594 (bus 7) | 603 (bus 7) | 608 (bus 7) | 658 (bus 7) | 715 (bus 7) | 768 (bus 7) | 823 (bus 7) |
| Total Line Losses (kW) | 464 | 446 | 389 | 285 | 201 | 136 | 89 | 62 | 53 | 117 | 121 | 131 | 149 | 174 | 206 |
| Total loss minimization (%) | 4% | 16% | 39% | 57% | 71% | 71% | 81% | 87% | 89% | 75% | 74% | 72% | 68% | 63% | 56% |
| Ratio $\varphi$ (%) | 89% | 83% | 75% | 69% | 63% | 59% | 56% | 55% | 58% | 56% | 55% | 55% | 55% | 55% | 55% |
| $P_{Actual}$ (kW) | 148 | 183 | 206 | 226 | 243 | 260 | 279 | 298 | 316 | 339 | 364 | 391 | 419 | 450 |

TABLE 11. Table of results for State-level hospital’s distribution network.

| Case | (PV-DG % from MD) | 1 | 2 (15) | 3 (20) | 4 (25) | 5 (30) | 6 (35) | 7 (40) | 8 (45) | 9 (Optimal) | 10 (50) | 11 (55) | 12 (60) | 13 (65) | 14 (70) | 15 (75) |
|------|-------------------|---|--------|--------|--------|--------|--------|--------|--------|------------|--------|--------|--------|--------|--------|--------|
| ZONE A | 1245 (kW) | Optimal | PV-DG in kW | 187 (bus 4) | 250 (bus 4) | 312 (bus 4) | 374 (bus 4) | 437 (bus 4) | 495 (bus 4) | 562 (bus 3) | 624 (bus 3) | 654 (bus 3) | 686 (bus 3) | 749 (bus 3) | 811 (bus 3) | 874 (bus 3) | 936 (bus 3) |
| Total Line Losses (kW) | 350 | 338 | 258 | 195 | 146 | 113 | 95 | 82 | 72 | 70 | 115 | 119 | 127 | 141 | 158 |
| Total loss minimization (%) | 3% | 26% | 44% | 58% | 68% | 73% | 73% | 79% | 80% | 67% | 66% | 64% | 60% | 58% | 57% | 56% | 55% |
| Ratio $\varphi$ (%) | 89% | 81% | 76% | 71% | 67% | 64% | 62% | 59% | 59% | 60% | 58% | 57% | 56% | 55% | 55% |
| $P_{Actual}$ (kW) | 166 | 204 | 236 | 264 | 292 | 320 | 346 | 371 | 383 | 409 | 436 | 463 | 491 | 519 |
TABLE 12. Table of results for District-level hospital.

| Case (PV-DG % from MD) | 1 (15) | 2 (20) | 3 (25) | 4 (30) | 5 (35) | 6 (40) | 7 (45) | 8 (50) | 9 (55) | 10 (60) | 11 (65) | 12 (70) | 13 (Optimal) | 14 | 15 |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|----------------|----|----|
| ZONE A (MD=1232kW)    |        |        |        |        |        |        |        |        |        |        |        |        | (Bus)         |    |    |
| PV-DG in kWp (bus 2)  | 185    | 246    | 308    | 370    | 431    | 493    | 554    | 616    | 678    | 739    | 801    | 862    | 885 (bus 5)   | 924|    |
| Total Line Losses (kW) | 648    | 645    | 642    | 511    | 401    | 313    | 243    | 193    | 164    | 138    | 99     | 73     | 62 (bus 5)    | 121|    |
| Total loss minimization (%) | 0.5%  | 1%     | 21%    | 38%    | 52%    | 63%    | 76%    | 75%    | 79%    | 83%    | 89%    | 90%    | 91% 81%       |    |    |
| Ratio ϕ (%)            | 91%    | 88%    | 80%    | 73%    | 67%    | 62%    | 59%    | 56%    | 54%    | 51%    | 49%    | 47%    | 47% 48%       |    |    |
| $P_{actual}$ (kW)      | 168    | 217    | 245    | 269    | 288    | 306    | 324    | 345    | 363    | 376    | 390    | 407    | 414 446       |    |    |

From the previous work which summarized in Table 6, the obtained $P_{DG}, L_1$, and $L_2$ have given access to measure the ratio $ϕ$ of useful energy consumption for load and loss minimization from the PV-DG generation which also represented by (3). Apparently, this also obtained $P_{actual}$ as a product of useful energy consumption yield for load and loss minimization multiplication outcome. For National-level hospital (Zone A), the percentage of $ϕ$ are equivalent to 89%, 83%, 75%, 69%, 63%, 59% and 56% for PV-DG with capacity of 15% of MD to 45% of MD in 5% ascending sequence respectively. While, $ϕ$ for the optimal case is equivalent to 55% and beyond this optimal value, $ϕ$ continue to decrease with the value of 58%, 56%, 55%, 55%, 55% and 55% for PV-DG with a capacity of 50% of MD to 75% of MD in 5% ascending sequence respectively. These $ϕ$ values are as highlighted with color in Table 10.

Subsequently, $ϕ$ is measured via (3) for State-level hospital which obtained $P_{actual}$ as a product of useful energy consumption yield for load and loss minimization multiplication outcome. For Zone A, the percentage of $ϕ$ are equivalent to 89%, 81%, 76%, 71%, 67%, 64%, 62% and 59% for PV-DG with capacity of 15% of MD to 50% of MD in 5% ascending sequence respectively. While, $ϕ$ for the optimal case is equivalent to 59% and beyond this optimal value, $ϕ$ continue to decrease with the value of 60%, 58%, 57%, 56% and 55% for PV-DG with a capacity of 50% of MD to 75% of MD in 5% ascending sequence respectively. These $ϕ$ values are as highlighted with color in Table 11.

Lastly, for the District-level hospital’s distribution network, $ϕ$ is measured via (3) which obtained $P_{actual}$ as a product of useful energy consumption yield for load and loss minimization outcome. The percentage of $ϕ$ are equivalent to 91%, 88%, 80%, 73%, 67%, 62%, 59%, 56%, 54%, 51%, 49% and 47% for PV-DG with capacity of 15% of MD to 70% of MD in 5% ascending sequence respectively. While, $ϕ$ for the optimal case is equivalent to 47% and beyond this optimal value, $ϕ$ is equal to 48% for PV-DG with 75% from MD. These $ϕ$ values are as highlighted with color in Table 12.

IV. RESULT AND DISCUSSIONS

The assessment is performed accordingly and the $ϕ$ values followed by the $P_{actual}$ results are obtained and compiled in Table 10, Table 11, and Table 12. Representing outcomes for National-level (Zone A), State-level (Zone A) and District-level hospital (Zone A) respectively including the previous input data of $P_{DG}, L_1$, and $L_2$. 
TABLE 14. The payback period worksheet for PP₁.

| Year | PV-DG Capacity (kWp) | Net Estimated Power Generation / Year (kWh) | Estimated Saving / Year (TNT Tariff = C) | OPEx / Year | Net Yearly Saving (Project) | Net Accumulated Saving | Payback Period |
|------|----------------------|--------------------------------------------|-----------------------------------------|-------------|-----------------------------|------------------------|---------------|
| 2017 | 0                    | N/A                                        | N/A                                     | N/A         | N/A                         | N/A                    | N/A           |
| 2018 | 1                    | 546                                        | 597,870.00                              | 27,300.00   | RM 217,826.70               | RM 217,826.70          | 217,826.70    |
| 2019 | 2                    | 542.18                                     | 593,684.91                              | 28,119.00   | RM 227,552.95               | 445,178.75            |               |
| 2027 | 10                   | 512.55                                     | 561,241.79                              | 35,620.31   | RM (982,800.00)             | RM (662,829.74)        | 1,677,453.97  |
| 2028 | 11                   | 508.96                                     | 557,313.09                              | 36,688.92   | RM 333,907.58               | 2,011,361.55          |               |
| 2029 | 12                   | 505.40                                     | 553,411.90                              | 37,789.58   | RM 348,446.08               | 2,359,807.63          |               |
| 2030 | 13                   | 501.86                                     | 549,558.02                              | 38,923.27   | RM 363,611.54               | 2,723,419.17          |               |
| 2031 | 14                   | 498.35                                     | 545,691.25                              | 40,090.97   | RM 379,430.81               | 3,102,849.98          |               |

B. IN-DEPTH EXPLANATORY FOR ϕ FINDING

For all hospital levels, the preliminary data from previous results (i.e. L₂, P DG, ϕ and P actual) are needed in graphical plotting to portray their conditions in a system network. Thus, the analysis of the overall results can be well explained as in Figs. 4 to 6 which focuses on the explanatory of the ϕ as
a key factor towards a more transparency in indicates performance which also potentially affects the payback period outcome. Furthermore, it is observed that, upon an increase of PV-DG capacity in the linear baseline, the useful energy consumption yield for load and loss minimization ($P_{actual}$) found to be underutilized and introduced a constant dropping of ratio $\phi$ (i.e. forming a wider gap between estimated PV-DG expanding baseline and $P_{actual}$). Hence, this has indicated lowering performance through a continuous PV-DG expanding utilization within the selected three distribution networks. The validation of the $\phi$ and $P_{actual}$ effect on the payback period outcome is examined through detailed assessment in later discussion.

### C. PAYBACK PERIOD MEASURE AS ACCORDANCE TO THE PV-DG PERFORMANCE OUTCOME

A few parameters on input variables were made into fixed values in defining the overall payback period for CAPEX and OPEX so that the focus of the outcome can be portrayed on the role of $\phi$ in enabling the length of the period. Some of these fixed parameters were adopted from the common-practices in estimation by the GBRS and PV-DG developers in Malaysia as follows:

- PV-DG installed capacity is set at identified expansion-limit (i.e., at an optimal point);
- PV-DG is assumed to generate a constant output power without intermittency;

#### TABLE 17. Comparison of payback period assessment between with and without proposed ratio consideration.

| Case  | $\phi$ (%) | Payback period without consideration of $\phi$ (Year) | Payback period with consideration of $\phi$ (Year) |
|-------|------------|-----------------------------------------------------|--------------------------------------------------|
| $PP_1$ | 55         | 14                                                  | 25                                                |
| $PP_2$ | 59         | 14                                                  | 24                                                |
| $PP_3$ | 47         | 14                                                  | 28                                                |

- PV-DG is assumed to generate maximum full-capacity power in 3 hours per day;
- CAPEX is estimated at RM5,000.00 per kWp basis;
- The values $P_{actual}$ were obtained which represent a product of multiplication outcome between $P_{DG}$ and $\phi$ as shown in Table 13.

Three sets of payback period assessment worksheets, i.e. $PP_1$, $PP_2$, and $PP_3$ are established for National, State and District-level hospital’s distribution networks respectively which involved in examining the role of the ratio $\phi$ towards measuring the payback period implication. In contrast, $PP_1$, $PP_2$, and $PP_3$ are determined as below:

- $PP_1$ – represented by payback period calculation without consideration of ratio $\phi$ versus payback period calculation with consideration of $\phi$ for National-level hospital (Zone A);
- $PP_2$ – represented by payback period calculation without consideration of ratio $\phi$ versus payback period...
TABLE 18. The proposed PR for an extended version.

| Sources                          | Current PR Formula                                      | Proposed PR for an extended version                      |
|----------------------------------|---------------------------------------------------------|---------------------------------------------------------|
|                                  | $PR = \frac{Y_c}{Y_r} = K_T \times K_G \times \eta_i$ | $PR = \frac{Y_c}{Y_r} = K_T \times K_G \times \eta_i \times \varphi$ |
| Haebrelin and Beutler [57]       |                                                         | Abbreviations:                                          |
|                                  |                                                         | $K_T$=Temperature correction factor,                     |
|                                  |                                                         | $K_G$=Generation correction factor,                      |
|                                  |                                                         | $\eta_i$=Inverter efficiency                           |
|                                  |                                                         | $\varphi =$ ratio of useful energy consumption for load  |
|                                  |                                                         | and line loss minimization                              |
|                                  |                                                         |                                                         |
|                                  | $R_P = \frac{Y_c}{Y_r}$                               | $R_P = \frac{Y_c}{Y_r}$                                |
|                                  |                                                         |                                                         |
| Kymakis et al. [58]              | $R_P = \eta_{deg} \times \eta_{tem} \times \eta_{soil} \times \eta_{net} \times \eta_{inv} \times \eta_{trans} \times \eta_{pcc}$ | $R_P = \eta_{deg} \times \eta_{tem} \times \eta_{soil} \times \eta_{net} \times \eta_{inv} \times \eta_{trans} \times \eta_{pcc} \times \varphi$ |
|                                  |                                                         | Abbreviations:                                          |
|                                  |                                                         | $\eta_{deg}$=panel degradation loss, $\eta_{tem}$=temp  |
|                                  |                                                         | losses, $\eta_{soil}$=soil loss, $\eta_{net}$=DC wiring |
|                                  |                                                         | and interconnection loss, $\eta_{inv}$=inverter loss,    |
|                                  |                                                         | $\eta_{trans}$=transformer loss, $\eta_{pcc}$=availability | and grid connection loss of the PV plant, $\varphi =$ ratio of useful energy consumption for load and line loss minimization |
|                                  |                                                         |                                                         |
|                                  |                                                         |                                                         |
| Ransome et al. [59]              | $PR = \frac{Y_c}{Y_r} = \frac{kWh_{AC}}{kWh_{p}}$    | $PR = \frac{Y_c}{Y_r} = \frac{kWh_{AC}}{kWh_{p}}$    |
|                                  |                                                         |                                                         |
|                                  | $kWh_{AC} = kWh_{AC,optimal} \times \frac{\text{insolation yearly}}{\text{insolation nominal}} \times \frac{\text{f downtime}}{\text{f downtime}} \times \frac{\text{f degradation}}{\text{f degradation}} \times \frac{\text{f plant}}{\text{f plant}} \times \frac{\text{f seasonal}}{\text{f seasonal}} \times \frac{\text{f shading}}{\text{f shading}} \times \frac{\text{f sos}}{\text{f sos}} \times \frac{\text{f 0}}{\text{f 0}}$ | $kWh_{AC} = kWh_{AC,optimal} \times \frac{\text{insolation yearly}}{\text{insolation nominal}} \times \frac{\text{f downtime}}{\text{f downtime}} \times \frac{\text{f degradation}}{\text{f degradation}} \times \frac{\text{f plant}}{\text{f plant}} \times \frac{\text{f seasonal}}{\text{f seasonal}} \times \frac{\text{f shading}}{\text{f shading}} \times \frac{\text{f sos}}{\text{f sos}} \times \frac{\text{f 0}}{\text{f 0}}$ |
|                                  |                                                         | Abbreviations:                                          |
|                                  |                                                         | $f$=uncertainty function due to downtime, panel degradation, soil, seasonal change, shading, balance of system effects, reference module calibration, flash effect, module binning and manufacturer declaration of the PV plant |
|                                  |                                                         |                                                         |
|                                  |                                                         |                                                         |
| PR-FACT Mack and Decker GmbH     | $PR = f_0 \times f_0 \times f_0 \times f_0 \times f_0$ | $PR = f_0 \times f_0 \times f_0 \times f_0 \times f_0$ |
|                                  |                                                         |                                                        |
|                                  | $f_0, f_1, f_2, \ldots , f_{10}$= correction factors related to: $f_1$ and $f_2$ = plane of angle irradiation; $f_3$ and $f_4$ = PV module; $f_5$ and $f_6$ = PV module configuration and DC wiring; $f_8, f_9$ and $f_{10}$ = AC wiring and transformer of the PV plant. | $f_0, f_1, f_2, \ldots , f_{10}$= correction factors related to: $f_1$ and $f_2$ = plane of angle irradiation; $f_3$ and $f_4$ = PV module; $f_5$ and $f_6$ = PV module configuration and DC wiring; $f_8, f_9$ and $f_{10}$ = AC wiring and transformer of the PV plant. |
|                                  |                                                         |                                                        |
|                                  | $f_{11}$= Useful energy consumption for load and line loss minimization |                                                        |

Calculation with consideration of $\varphi$ for State-level hospital (Zone A);

- $PP_3$ – represented by payback period calculation 
  without consideration of ratio $\varphi$ versus payback period calculation with consideration of $\varphi$ for District-level hospital (Zone A);

Moreover, the estimated CAPEX and OPEX are listed in Table 7 and Table 8 respectively. The obtained input parameter values for $PP_1$, $PP_2$, and $PP_3$ are shown in Table 13.

The payback period worksheet for $PP_1$, $PP_2$, and $PP_3$ was assessed and the final result is as shown in Table 14, Table 15 and Table 16 respectively. Without consideration of $\varphi$, the achieved payback period outcome for PV-DG installation is equal to the 14th year for both $PP_1$, $PP_2$, and $PP_3$, regardless of differences in PV-DG capacity value that being utilized and also regardless of differences in the extensiveness of radial distribution network. In other words, the estimation for 546 kWp, 654 kWp, and 845 kWp through $PP_1$, $PP_2$, and $PP_3$ cases respectively had resulted in the same payback period for CAPEX and OPEX if $\varphi$ is not factored in the calculation.

On the other hand, the assessment with consideration of $\varphi$ has revealed the actual payback period milestone as in $PP_1$, $PP_2$, and $PP_3$ where their outcomes are made comparable with the previous unconsidered $\varphi$ based findings. The comparison result showed that the actual payback period for $PP_1$, $PP_2$, and $PP_3$ is equivalent to 25 years, 24 years and 28 years for PV-DG installation respectively. Table 17 summarized the comparison result. In addition, the differences of findings were driven by the differences of obtained input parameters as highlighted with the red-dotted line in Tables 14 to 15.

Through the discrepancy of estimated payback period outcome within $PP_1$, $PP_2$, and $PP_3$, the results confirmed the role and the importance in considering the $\varphi$ based findings in determining the more transparency figure for the payback period milestone (CAPEX and OPEX) which had more advantage in the application as compared with the other way approach of estimation. In contrast, the presented ratio $\varphi$ of 55%, 59%, and 47% had portrayed the more accurate
payback period outcome, i.e. 25 years, 24 years and 28 years respectively as compared to 14 years via the other way approach of estimation without ϕ consideration.

The findings in the previous work [33], has highlighted the optimal value which depends on the overall performance of PV-DG integration in forming a bidirectional of P into these distribution networks as highlighted in [85]. Similarly, the same reason can relate with the payback period outcome since the determination of the ratio values was driven by the line loss input determined by the type and extensiveness of the radial distributed network in terms of R/X value as referred to Box [86], also the P and Q load data in accordance to Van Thong et al. [50] and Bawan [87].

D. PROPOSED ADDITIONAL VALUE TO THE CURRENT PR FORMULATION TOWARDS EXTENDED VERSION

Due to prudence used in the sample selection and data analysis, the PV-DG performance indicator via the ratio ϕ in obtaining the Pactual has shown the proportionate contribution to the milestone of the overall payback period through assessment via three selected distribution networks. On the other hand, the IEC 61724 determination on the complete PV-DG system as of Fig. 1 which focuses on the voltage VL and current IL towards load consumption [47], has highlighted the needs of the proposed ratio in filling the gaps for precision performance indicator as previous-discussed. Therefore, a performance measure for a complete PV-DG system via PR formulation shall consider the specific total line losses contribution, through the formed of the ratio ϕ as shown in Table 18 where a few selected formulations from the PR review of Table 4 is proposed to be revolutionized for an extended version.

V. CONCLUSION

The previous work in [33] via total line losses measure had successfully portrayed the PV-DG expansion-limit due to the need for increasing the current PV-DG capacity beyond the GBRs base case. In this study, the conducted assessment on the selected PV-DG capacity has introduced the additional effective parameter on top of the loss minimization contribution, i.e. the performance measure tailored for distribution network from selected Malaysian public hospital. The proposed ϕ value has been tested and highlighted in the previous assessment which has projected the more transparent payback period outcome for the CAPEX and OPEX. Moreover, this also significantly enabling a potential gap for future assessment towards further improvement in PDG capacity setting for higher ϕ achievement. The assessment through PP1, PP2, and PP3 had overcome with the final result as shown in Table 14, Table 15, and Table 16 respectively which zooming on the role of ϕ as an enabler towards the payback period achievement is legitimate which proven by the calculation in the worksheet. In contrast, the presence of ϕ in the linear PV-DG expanding approach at the optimal point had clarified the actual payback period, i.e. 25 years, 24 years and 28 years respectively which overwrite the 14 years outcome via the other way approach of estimation without ϕ consideration. Finally, the payback period for CAPEX and OPEX is an important milestone in many Government Agencies due to their designated budget allocation and collection through dedicated 5 years in each of Malaysia Plan periods. The monetary account planning in this sense by MoH for PV-DG design and installation at the selected public hospital can be well-adjusted as according to the desired payback period since time is of constraint and inevitable in the project management. Therefore, the desired performance specification in the form of PR can later be adjusted to suit the timeline and payback period given via a downstream-to-upstream method for a well-justified outlook and workable for practical application by MoH.

Despite due prudence used in the sample selection and data analysis, this paper still has some limitations, i.e. in-depth financial analysis other than the one that has been provided in this research is not considered in the payback period assessment and the PR proposal. Other than that, the input parameter from previous work was also limited by the use of a quantitative approach since the simulation of the technical data role as the main part of the study. However, qualitative analysis to measure the significance of the PV-DG expansion in GBRs may provide different results. The combination of both quantitative and qualitative measures may also provide a wider contribution in terms of the significant improvement in GBRs tools.

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