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Effect of Design Parameters

PMSM with Multilevel Inverter

Highlights

Low Probability of Intercept

Model-Based Predictive Direct

Discovering Thoughts, Inventing Future

VOLUME 18 ISSUE 2 VERSION 1.0

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Low Probability of Intercept Frequency Hopping Signal Characterization Comparison using the Wigner Ville Distribution and the Choi Williams Distribution

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Abstract- Low probability of intercept radar signals, which are often challenging to detect and characterize, have as their objective 'to see and not be seen'. Digital intercept receivers are currently moving from Fourier-based techniques to classical time-frequency techniques for the analysis of low probability of intercept radar signals. This paper presents the novel approach of characterizing low probability of intercept frequency hopping radar signals through utilization and direct comparison of the Wigner Ville Distribuion versus the Choi Williams Distribution. Two different frequency hopping low probability of intercept radar signals were analyzed (4-component and 8-component). The following metrics were used for evaluation: percent error of: carrier frequency, modulation bandwidth, modulation period, and time-frequency localization. Also used were: percent detection, lowest signaltonoise ratio for signal detection, and plot (processing) time.

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LOWPROBABILITYOFINTERCEPTFREQUENCYHOPPINGSIGNALCHARACTERIZATIONCOMPARISONUSINGTHEWIGNERVILLEDISTRIBUTIONANDTHECHOIWILLIAMSDISTRIBUTION1

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Low Probability of Intercept Frequency Hopping Signal Characterization Comparison using the Wigner Ville Distribution and the Choi Williams Distribution[1]

Daniel L. Stevens [α] & Stephanie A. Schuckers [σ]

Abstract- Low probability of intercept radar signals, which are often challenging to detect and characterize, have as their objective 'to see and not be seen'. Digital intercept receivers are currently moving from Fourier-based techniques to classical time-frequency techniques for the analysis of low probability of intercept radar signals. This paper presents the novel approach of characterizing low probability of intercept frequency hopping radar signals through utilization and direct comparison of the Wigner Ville Distribuion versus the Choi Williams Distribution. Two different frequency hopping low probability of intercept radar signals were analyzed (4-component and 8-component). The following metrics were used for evaluation: percent error of: carrier frequency, modulation bandwidth, modulation period, and time-frequency localization. Also used were: percent detection, lowest signal-to-noise ratio for signal detection, and plot (processing) time. Experimental results demonstrate that overall, the Wigner Ville Distribution produced more accurate characterization metrics than the Choi Williams Distribution. An improvement in performance could potentially translate into saved equipment and lives.

I. Introduction

A low probability of intercept (LPI) radar that uses frequency hopping techniques changes the transmitting frequency in time over a wide bandwidth in order to prevent an intercept receiver from intercepting the waveform. The frequency slots used are chosen from a frequency hopping sequence, and this unknown sequence gives the radar the advantage over the intercept receiver in terms of processing gain. The frequency sequence appears random to the intercept receiver, therefore the possibility of it following the changes in frequency is remote [PAC09]. This prevents a jammer from jamming the transmitted frequency [ADA04]. Frequency hopping radar performance depends only slightly on the code used, given that certain properties are met. This allows for a larger assortment of codes, making it more difficult to intercept.

Time-frequency signal analysis includes the analysis and processing of signals with time-varying frequency content. These signals are best represented by a time-frequency distribution [PAP94], [HAN00], which displays how the energy of the signal is distributed over the two-dimensional time-frequency plane [WEI03], [LIX08], [OZD03]. Processing of the signal may then exploit the features produced by the concentration of signal energy in two dimensions (time and frequency), vice one dimension (time or frequency) [BOA03], [LIY03]. Since noise has a tendency to spread out evenly over the time-frequency domain, while signals tend to concentrate their energies within limited time intervals and frequency bands; the local SNR of a noisy signal can be improved by using time-frequency analysis [XIA99]. In addition, the intercept receiver can increase its processing gain by implementing time-frequency signal analysis [GUL08].

Time-frequency distributions can be beneficial for the visual interpretation of signal dynamics [RAN01]. An experienced operator may be better able to detect a signal and extract its parameters by examining the time-frequency distribution [ANJ09].

a) Wigner Ville Distribution (WVD)

One of the most prominent members of the time-frequency analysis techniques family is the WVD. The WVD satisfies a large number of desirable mathematical properties. In particular, it is always real-valued, preserves time and frequency shifts, and satisfies marginal properties [AUG96], [QIA02]. The WVD, which is a transformation of a continuous time signal into the time-frequency domain, is computed by

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correlating the signal with a time and frequency translated version of itself, making it bilinear. The WVD exhibits the highest signal energy concentration in the time-frequency plane [WIL06]. By using the WVD, an intercept receiver can come close to having a processing gain near the LPI radar's matched filter processing gain [PAC09]. The WVD also contains cross term interference between every pair of signal components, which may limit its applications [GUL07], [STE96], and which can make the WVD time-frequency representation hard to read, especially if the components are numerous or close to each other, and the more so in the presence of noise [BOA03]. This lack of readability can in turn translate into decreased signal detection and parameter extraction metrics, potentially placing the intercept receiver signal analyst in harm's way.

The WVD of a signal $x(t)$ is given in equation (1) as:

$$W_x(t,f) = \int_{-\infty}^{+\infty} x(t+\frac{\tau}{2})x^*\left(t-\frac{\tau}{2}\right)e^{-j2\pi f\tau}\,d\tau \qquad (1)$$

or equivalently in equation (2) as:

$$W_x(t,f) = \int_{-\infty}^{+\infty} X(f+\frac{\xi}{2})X^*\left(f-\frac{\xi}{2}\right)e^{j2\pi\xi t}d\xi \qquad (2)$$

b) Choi Williams Distribution (CWD)

The CWD is a member of the Cohen's class of time-frequency distributions which use smoothing kernels [GUL07] to help reduce cross-term interference so prevalent in the WVD [BOA03], [PAC09], [UPP08]. The reduction in cross-term interference can make the time-frequency representation more readable and can make signal detection and parameter extraction more accurate. The down-side is that the CWD, like all members of Cohen's class, is faced with an inevitable trade-off between cross-term reduction and time-frequency localization. Because of this, the signal detection and parameter extraction benefits gained by the cross-term reduction may be offset by the decrease in time-frequency localization (smearing or widening of the signal).

The CWD of a signal $x(s)$is given in equation (3) as:

$$CW_x(t,f) = \sqrt{\frac{2}{\pi}}\iint_{-\infty}^{+\infty}\frac{\sigma}{|\tau|}e^{-2\sigma^2(s-t)^2/\tau^2}\,x\left(s+\frac{\tau}{2}\right)x^*\left(s-\frac{\tau}{2}\right)e^{-j2\pi f\tau}\,ds\,d\tau \qquad (3)$$

As can be seen from equation (3), the CWD uses an exponential kernel in the generalized class of bilinear time-frequency distributions. Choi and Williams introduced one of the earliest 'new' distributions [CHO89], which they called the Exponential Distribution or ED. This new distribution overcomes several drawbacks of the Spectrogram and the WVD, providing decent localization with suppressed interferences [WIL92], [GUL07], [UPP08]. Interference terms tend to lie away from the axes in the ambiguity plane, while auto terms (signals) tend to lie on the axes. The Spectrogram kernel attenuates everything away from the $(0,0)$ point, the WVD kernel passes everything, and the CWD kernel passes everything on the axes and attenuates away from the axes. Thus, the CWD generally attenuates interference terms [PAC09], [HLA92]. This provides its reduced interference characteristic. The Spectrogram reduces interference also, but at a cost to the signal concentration.

II. Methodology

The methodologies detailed in this section describe the processes involved in obtaining and comparing metrics between the classical time-frequency analysis techniques of the Wigner Ville Distribution and the Choi Williams Distribution for the detection and characterization of low probability of intercept frequency hopping radar signals.

The tools used for this testing were: MATLAB (version 7.12), Signal Processing Toolbox (version 6.15), Wavelet Toolbox (version 4.7), Image Processing Toolbox (version 7.2), Time - Frequency Toolbox (version 1.0).

Testing (which was accomplished on a desktop computer) was performed for 2 different waveforms (4 component frequency hopping, 8 component frequency hopping). For each waveform, parameters were chosen for academic validation of signal processing techniques. Due to computer processing resources they were not meant to represent real-world values. The number of samples for each test was chosen to be 512, which seemed to be the optimum size for the desktop computer. Testing was performed at three different SNR levels: 10dB, 0dB, and the lowest SNR at which the signal could be detected. The noise added was white Gaussian noise, which best reflects the thermal noise present in the IF section of an intercept receiver [PAC09]. Kaiser windowing was used, when windowing was applicable. 50 runs were performed for each test, for statistical purposes. The plots included in this paper were done at a threshold of 5% of the maximum intensity and were linear scale (not dB) of analytic

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(complex) signals; the color bar represents intensity. The signal processing tools used for each task were the Wigner Ville Distribution and the Choi Williams Distribution.

Task 1 consisted of analyzing a frequency hopping (prevalent in the LPI arena [AMS09]) 4-component signal whose parameters were: sampling frequency=5KHz; carrier frequencies=1KHz, 1.75KHz, 0.75KHz, 1.25KHz; modulation bandwidth=1KHz; modulation period=.025sec.

Task 2 was similar to Task 1, but for a frequency hopping 8-component signal, whose parameters were: sampling frequency=5KHz; carrier frequencies= 1.5KHz, 1KHz, 1.25KHz, 1.5KHz, 1.75KHz, 1.25KHz, 0.75KHz, 1KHz; modulation bandwidth=1KHz; modulation period=.0125sec.

After each particular run of each test, metrics were extracted from the time-frequency representation. The different metrics extracted were as follows:

1) Plot (processing) time: Time required for plot to be displayed.
2) Percent detection: Percent of time signal was detected - signal was declared a detection if any portion of each of the signal components (4 or 8 signal components) exceeded a set threshold (a certain percentage of the maximum intensity of the time-frequency representation).

Threshold percentages were determined based on visual detections of low SNR signals (lowest SNR at which the signal could be visually detected in the time-frequency representation) (see Figure 1).

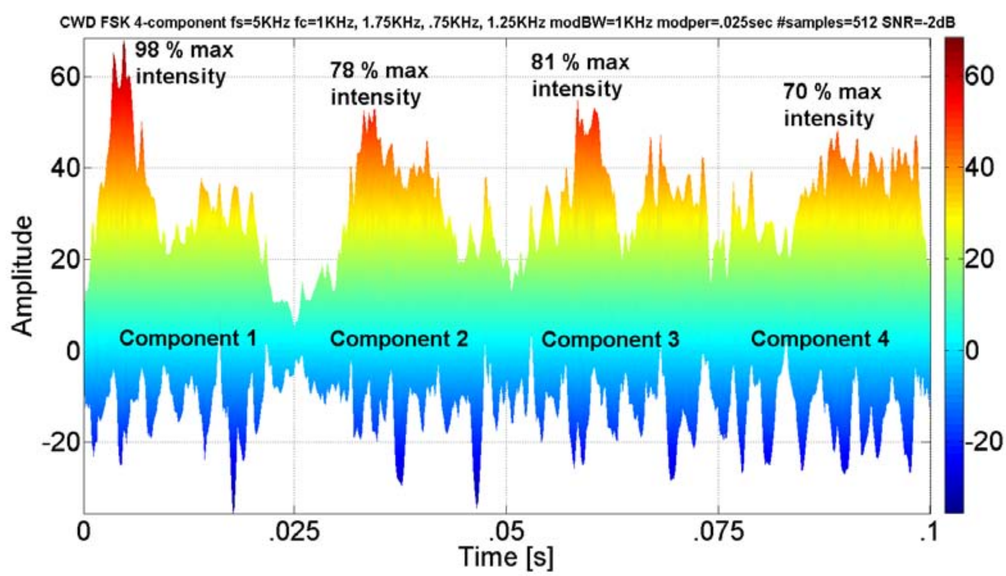

Figure 1: Threshold percentage determination. This plot is an amplitude vs. time (x-z view) of the CWD of a 4-component frequency hopping signal (512 samples, SNR= -2dB). For visually detected low SNR plots (like this one), the percent of max intensity for the peak z-value of each of the signal components was noted (here 98%, 78%, 81%, 70%), and the lowest of these 4 values was recorded (70%). Ten test runs were performed for this time-frequency analysis tool (CWD) for this waveform. The average of these recorded low values was determined and then assigned as the threshold for that particular time-frequency analysis tool. Note – the threshold for the CWD is 70%.

Thresholds were assigned as follows: CWD (70%); WVD (4-component FSK) (50%); WVD (8-component FSK) (20%).

For percent detection determination, these threshold values were included in the time-frequency plot algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the signal components was visible (see Figure 2).

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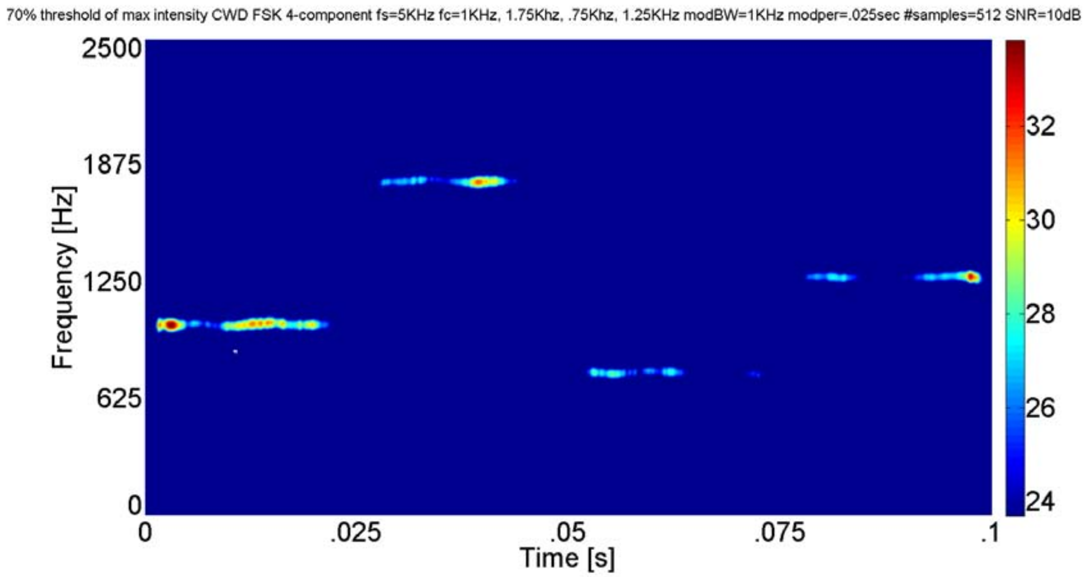

Figure 2: Percent detection (time-frequency). CWD of 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 70%. From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 FSK signal components was visible.

3) Carrier frequency: The frequency corresponding to the maximum intensity of the time-frequency representation (there are multiple carrier frequencies (4 or 8) for the frequency hopping waveforms).

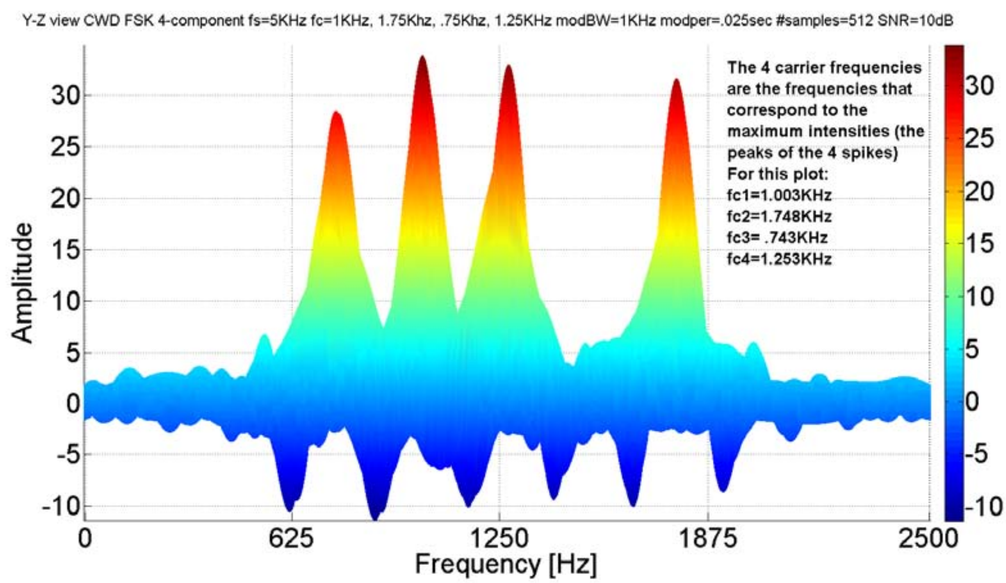

Figure 3: Determination of carrier frequency. CWD of a 4-component frequency hopping signal (512 samples, SNR=10dB). From the frequency-intensity (y-z) view, the 4 maximum intensity values (1 for each carrier frequency) are manually determined. The frequencies corresponding to those 4 max intensity values are the 4 carrier frequencies (for this plot fc1=1003 Hz, fc2=1748Hz, fc3=743Hz, fc4=1253Hz).

4) Modulation bandwidth: Distance from highest frequency value of signal (at a threshold of 20% maximum intensity) to lowest frequency value of signal (at same threshold) in Y-direction (frequency).

The threshold percentage was determined based on manual measurement of the modulation bandwidth of the signal in the time-frequency representation. This was accomplished for ten test runs of each time-frequency analysis tool (CWD and WVD), for each of the 2 waveforms. During each manual measurement, the max intensity of the high and low measuring points was recorded. The average of the max intensity values for these test runs was 20%. This was adopted as the threshold value, and is representative of what is obtained when performing manual measurements. This 20% threshold was also adapted for determining the modulation period and the time-frequency localization (both are described below).

For modulation bandwidth determination, the 20% threshold value was included in the time-frequency plot algorithms so that the threshold could be applied automatically during the plotting process. From the threshold plot, the modulation bandwidth was manually measured (see Figure 4).

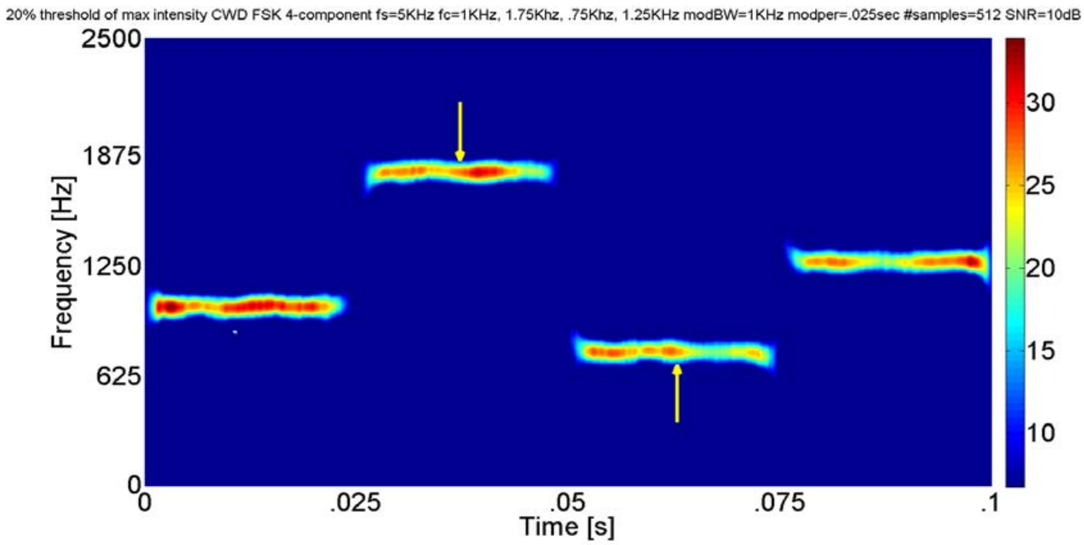

Figure 4: Modulation bandwidth determination. CWD of a 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the modulation bandwidth was measured manually from the highest frequency value of the signal (top yellow arrow) to the lowest frequency value of the signal (bottom yellow arrow) in the y-direction (frequency).

5) Modulation period: From Figure 5 (which is at a threshold of 20% maximum intensity), the modulation period is the manual measurement of the width of each of the 4 frequency hopping signals in the x-direction (time), and then the average of the 4 signals is calculated.

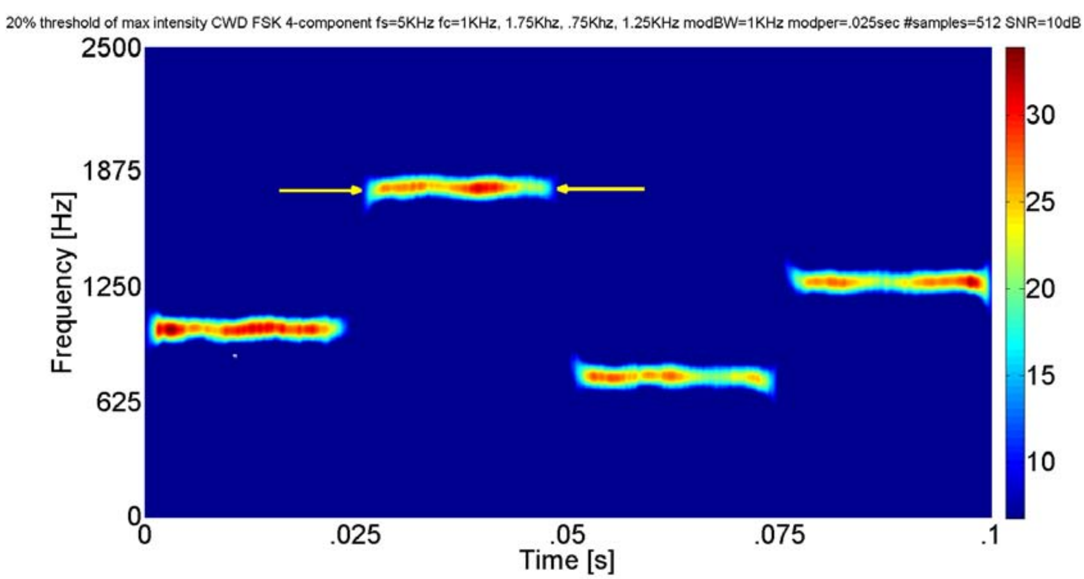

Figure 5: Modulation period determination. CWD of a 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the modulation period was measured manually from the left side of the signal (left yellow arrow) to the right side of the signal (right yellow arrow) in the x-direction (time). This was done for all 4 signal components, and the average value was determined.

6) Time-frequency localization: From Figure 6, the time-frequency localization is a manual measurement (at a threshold of 20% maximum intensity) of the 'thickness' (in the y-direction) of the center of each of the 4 frequency hopping signal components, and then the average of the 4 values are determined. The average frequency 'thickness' is then converted to: percent of the entire y-axis.

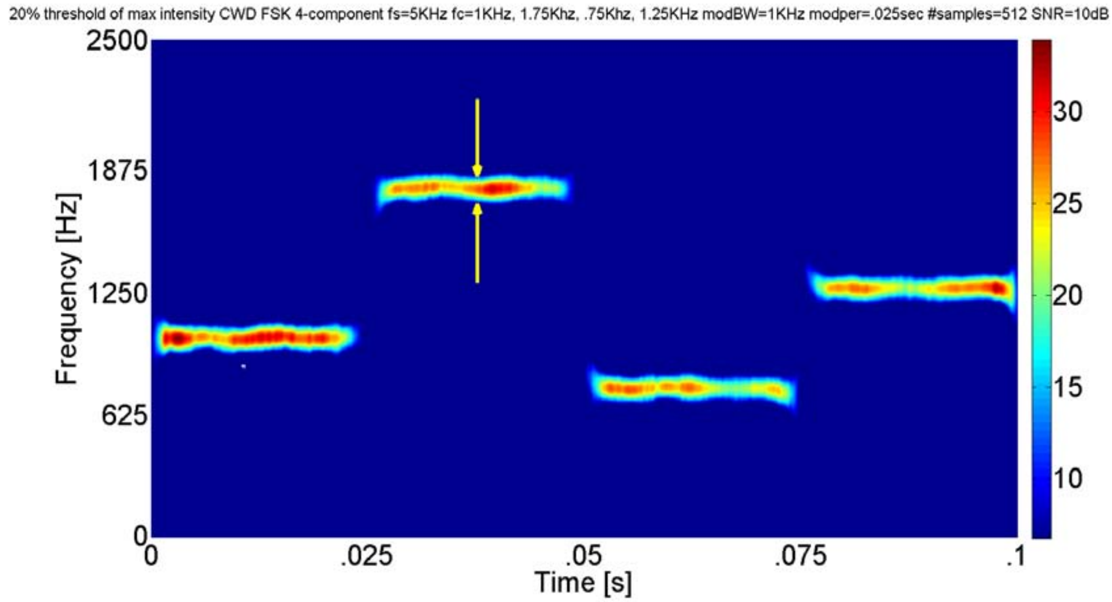

Figure 6: Time-frequency localization determination for the CWD of a 4-component frequency hopping signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the time-frequency localization was measured manually from the top of the signal (top yellow arrow) to the bottom of the signal (bottom yellow arrow) in the y-direction (frequency). This frequency 'thickness' value was then converted to: % of entire y-axis.

7) Lowest detectable SNR: The lowest SNR level at which at least a portion of each of the signal components exceeded the set threshold listed in the percent detection section above.

For lowest detectable SNR determination, these threshold values were included in the time-frequency plot algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the signal components was visible. The lowest SNR level for which the signal was declared a detection is the lowest detectable SNR (see Figure 7).

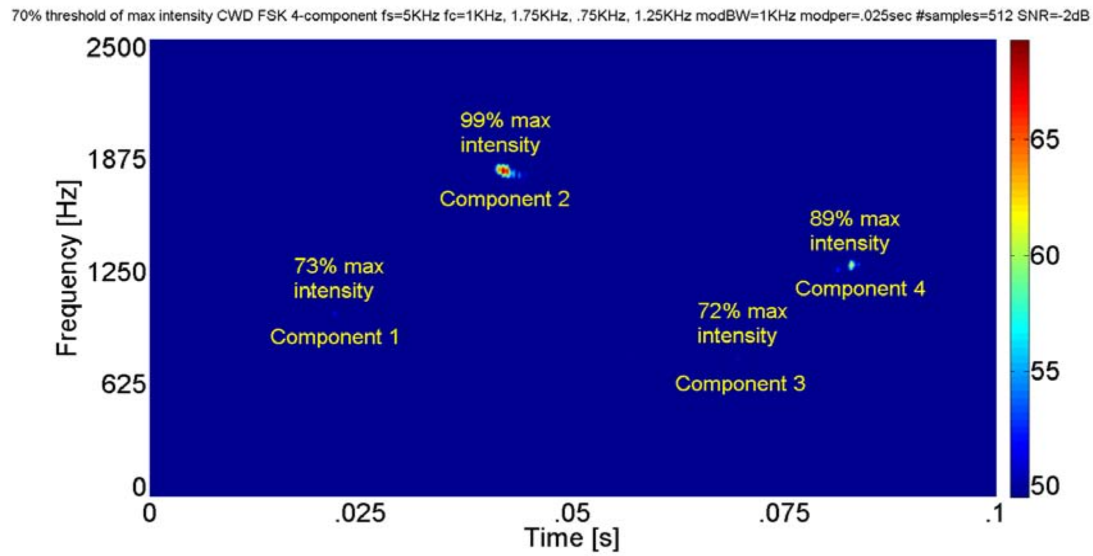

Figure 7: Lowest detectable SNR (time-frequency). CWD of 4-component frequency hopping signal (512 samples, SNR=-2dB) with threshold value automatically set to 70%. From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 frequency hopping signal components was visible. Note that the signal portion for the 73% max intensity and the 72% max intensity (just below the 'n' in 'intensity' for each case) is barely visible because the threshold for the CWD is 70%. For this case, just a slightly lower SNR would have been a non-detect. Compare to Figure 2, which is the same plot, except that it has an SNR level equal to 10dB.

The data from all 50 runs for each test was used to produce the actual, error, and percent error for each of these metrics listed above.

The metrics from the WVD were then compared to the metrics from the CWD. By and large, the WVD outperformed the CWD, as will be shown in the results section.

III. Results

Table 1 presents the overall test metrics for the two classical time-frequency analysis techniques used in this testing (WVD versus CWD).

Table 1: Overall test metrics (average percent error: carrier frequency, modulation bandwidth, modulation period; average: time-frequency localization-y (as percent of y-axis), percent detection, lowest detectable SNR, plot time) for the two classical time-frequency analysis techniques (WVD versus CWD).

Parameters	WVD	CWD
carrier frequency	0.19%	0.62%
modulation bandwidth	5.97%	17.92%
modulation period	17.01%	17.05%
time-frequency localization-y	2.04%	6.78%
percent detection	90.7%	88.7%
lowest detectable SNR	-2.0db	-2.2db
plottime	6382s	10.16s

From Table 1, the WVD outperformed the CWD in average percent error: carrier frequency (0.19% vs. 0.62%), modulation bandwidth (5.97% vs. 17.92%), modulation period (17.01% vs. 17.05%), and time-frequency localization (y-direction) (2.04% vs. 6.78%);and in average: percent detection (90.7% vs.

88.7%), while the CWD outperformed the WVD in lowest detectable SNR (-2.2db vs. -2.0db) and average plot time (10.16s vs. 6382s).

Figure 8 shows comparative plots of the WVD vs. the CWD (4 component frequency hopping) at SNRs of 10dB (top), 0dB (middle), and -2dB (bottom).

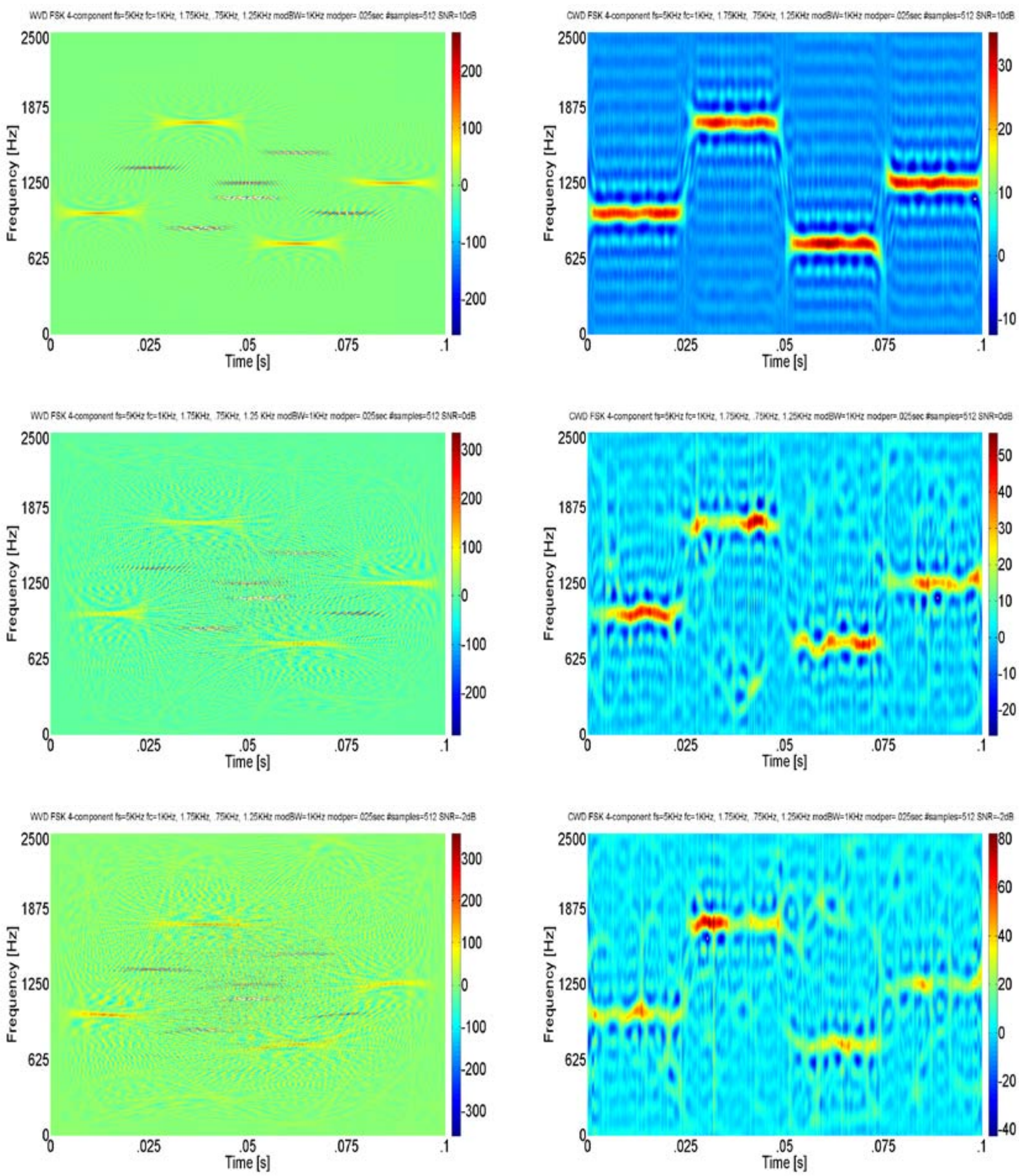

Figure 8: Comparative plots of the 4-component frequency hopping low probability of intercept radar signals (WVD (left-hand side) vs. CWD (right-hand side)). The SNR for the top row is 10dB, for the middle row is 0dB, and for the bottom row is -2dB. The WVD signals are more localized ('thinner') than the CWD signals. However, the WVD does have a cross-term half-way between each signal, which, to the untrained eye, could be misinterpreted as a 'cross-term false positive' (the 6 blue 'false signals') – the more so as the SNR gets lower.

IV. Discussion

This section will elaborate on the results from the previous section.

From Table 1, the WVD outperformed the CWD in average percent error: carrier frequency (0.19% vs. 0.62%), modulation bandwidth (5.97% vs. 17.92%), and modulation period (17.01% vs. 17.05%) -and in average: time-frequency localization-y (as a percent of y-axis) (2.04% vs. 6.78%) and percent detection (90.7% vs. 88.7%). These results are by and large a result of the WVD signal being much more localized signal than the

CWD signal. The CWD's 'thicker' signal is a result of its cross-term reduction - at the expense of signal localization.

The CWD outperformed the WVD in average: plot time (10.16s vs. 6382s) and lowest detectable SNR (-2.2db vs. -2.0db). The combination of the CWD's reduction of cross-term interference along with the WVD being very computationally complex [MIL02] are the grounds for the CWD's better plot time. In addition, lowest detectable SNR is based on visual detection in the Time-Frequency representation. Figures 8 and 9 show that, for the WVD plots, as the SNR gets lower, it gets more difficult to distinguish between the actual signals and the cross-term interference. However, for the CWD plots there is no cross-term interference to confuse with the actual signals, making the CWD signals, though not as localized, easier to detect than the WVD signals- at these lower SNRs.

The WVD might be used in a scenario where you need good signal localization in a fairly low SNR environment, without tight time constraints. The CWD might be used in a scenario where a short plot time is necessary, and where signal localization is not an issue. Such a scenario might be a 'quick and dirty' check to see if a signal is present, without precise extraction of its parameters.

V. Conclusions

Digital intercept receivers, whose main job is to detect and extract parameters from low probability of intercept radar signals, are currently moving away from Fourier-based analysis and towards classical time-frequency analysis techniques, such as the WVD and the CWD, for the purpose of analyzing low probability of intercept radar signals. Based on the research performed for this paper (the novel direct comparison of the WVD versus the CWD for the signal analysis of low probability of intercept frequency hopping radar signals) it was shown that the WVD by and large outperformed the CWD for analyzing these low probability of intercept radar signals - for reasons brought out in the discussion section above. More accurate characterization metrics could well translate into saved equipment and lives.

Future plans include analysis of an additional low probability of intercept radar waveform (triangular modulated FMCW), again using the WVD and the CWD as time-frequency analysis techniques.

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Keywords: electrical drives, predictive current control (PCC), predictive torque control (PTC), permanent magnet synchronous motor (PMSM), induction motor, 15-level h-bridge multilevel inverter, voltage source inverter (VSI).

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Suraj Karpe [α], Sanjay A. Deokar [σ] & Arati M. Dixit [ρ]

Abstract- In Power Electronics, Predictive Current control (PCC) and Predictive Torque control (PTC) methods are advanced control strategy. To control a Permanent Magnet Synchronous motor machine (PMSM) or induction machine (IM), the predictive torque control (PTC) method evaluates the stator flux and electromagnetic torque in the cost function and Predictive Current control (PCC) [1] considers the errors between the current reference and the measured current in the cost function. The switching vector selected for the use in IGBTs minimizes the error between the references and the predicted values. The system constraints can be easily included [4, 5]. The weighting factor is not necessary. Both the PTC and PCC methods are most useful direct control methods with PMSM method gives 10% to 30% more torque than an induction motor also not require modulator [3]. Induction motor work on only lagging power factor means it can produce only 70-90% of torque produced by PMSM with same current. PCC and PTC method with 15-level H-bridge multilevel inverter using PMSM reduces 23% more THD in torque, speed and stator current compared to PCC and PTC method with 15-level H-bridge multilevel inverter using induction motor [21]. Switching losses are minimized because the transistors are only switched when it is needed to keep torque and flux within their bounds. The switching pattern of semiconductor switches used to get better performance of multilevel inverter. In this paper, the PTC and PCC methods with 15-level H-bridge multilevel inverter using PMSM and IM are carried out; gives excellent torque and flux responses, robust, and stable operation achieved compared to the PTC and PCC methods with 2-level voltage source inverter. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states [8].

Keywords: *electrical drives, predictive current control (PCC), predictive torque control (PTC), permanent magnet synchronous motor (PMSM), induction motor, 15-level h-bridge multilevel inverter, voltage source inverter (VSI).*

I. Introduction

Current control (PCC) and Predictive Torque control (PTC) methods are promising methods. Along reducing torque ripples, the FCS-PTC method also illustrates a number of advantages, like the easy inclusion of constraints, easy implementation, straightforward, algorithm and fast dynamic responses. The basic concept of model predictive direct torque control (MPDTC) method is to calculate the required control signals in advance [6]. In the MPDTC method, pulse width modulation is needless. The inverter model is required in the control method. During MPDTC, the PTC and PCC method calculates all possible voltage vectors within one sampling interval and selects the best one by using an optimization cost function [7]. To date, the PCC and PTC methods have been adapted in many operational situations and widely investigated, as given in the articles [8], [9].

Now a day, if a semiconductor switch is directly connected to the system with Medium sized voltage grids will create problems. To solve this problem, a multilevel inverter topology has been introduced as an alternative solution for medium voltage and high voltage and extra high voltage power situations. A multilevel inverter can be used renewable energy as a source and can achieve high power rating. So, solar, fuel cells and wind like renewable energy sources can be easily interfaced to a multilevel inverter structure for a high power application. The multilevel inverter concept has been used for past three decades. Multilevel inverter (MLI) has become more popular over the year and magnetized considerable affection in recent years. The MLI generating a stepped voltage waveform which has compressed the harmonic distortion because of inclusion a group of power semiconductor devices and capacitor as voltage sources. The number of merits of MLI is its ability to reduce voltage stress on power switches, dv/dt ratio and common mode voltage, thus improving the quality of the output [1]. There are various topologies of MLI such as Diode Clamped Multilevel Inverter, Cascaded Multilevel Inverter and Flying Capacitor Multilevel Inverter. Out of which H-Bridge multilevel inverter has various advantages such as generate output voltages with extremely low distortion, and lower and draw input current with very low distortion, generate smaller common-mode (CM)

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voltage, thus reducing the stress on the motor bearings and can operate with a lower switching frequency.

In this paper, the PTC and PCC methods with 15-level H-bridge multilevel inverter using PMSM and IM are carried out by simulation method and compared with the PTC and PCC methods with 2-level voltage source inverter. PCC and PTC method with 15-level H-bridge multilevel inverter using PMSM reduces 23% THD in torque, speed and stator current compared to PCC and PTC method with 15-level H-bridge multilevel inverter using an induction motor [10] [24]. Switching losses are minimized because the transistors are only switched when it is needed to keep torque and flux within their bounds. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states [8].

II. Modeling of PMSM

The mathematical model of a PMSM given by complex equations in the rotor reference frame is as below:

Voltage equations are given by:

$$V_d = R_s i_d - \omega_r \lambda_q + \frac{d\lambda_d}{dt} \quad [1]$$

$$V_q = R_s i_q - \omega_r \lambda_d + \frac{d\lambda_q}{dt} \quad [2]$$

Flux linkage is given by

$$\lambda_q = L_q i_q \quad [3]$$

$$\lambda_d = L_d i_d + \lambda_f \quad [4]$$

Substituting Equation 3 and 4 in 1 and 2, we get,

$$V_q = R_s i_q - \omega_r \left(L_d i_d + \lambda_f\right) + \frac{d(L_q i_q)}{dt} \quad [5]$$

$$V_d = R_s i_d - \omega_r L_q i_q . + \frac{d}{dt}\left(L_d i_d + \lambda_f\right) \quad [6]$$

Arranging equation 5 and 6 in matrix form,

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_s + \frac{dL_q}{dt} & \omega_r L_d \\ -\omega_r L_q & R_s + \frac{dL_d}{dt} \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \frac{d\lambda_f}{dt} \end{pmatrix} \quad [7]$$

The developed motor torque is being given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_d i_q - \lambda_q i_d\right) \quad [8]$$

$$T_e = \frac{3}{4} P\left[\lambda_f i_q + \left(L_d - L_q\right) i_q i_d\right] \quad [9]$$

$$T_e = T_L + B\omega_m + J\frac{d\omega_m}{dt} \quad [10]$$

Solving for rotor mechanical speed from equation 10, we get,

$$\omega_m = \int \left(\frac{T_e - T_L - B\omega_m}{J}\right) dt \quad [11]$$

And rotor electrical speed is

$$\omega_r = \omega_m \left(\frac{P}{2}\right) \quad [12]$$

III. Cascaded H-Bridge Multilevel Inverter

The output phase voltage generalized use as

$$u = u_{a1} + u_{a2} + u_{a3} + u_{a4} + u_{a5} \dots \dots \dots + u_{an} \quad [13]$$

The Fourier transform of the corresponding stepped waveform follows [9, 5]:

$$\mathrm{U}(\omega t) = \frac{4\mathrm{U_{dc}}}{\pi} \sum [\cos(\mathrm{n}\theta_1) + \cos(\mathrm{n}\theta_2) + \dots + \cos(\mathrm{n}\theta_l)] \frac{\sin(\mathrm{n}\omega t)}{\mathrm{n}} \quad [14]$$

where n = 1,3,5,7.

By choosing conducting angles, θ_1, θ_2,…….,θ_l, such that the total harmonic distortion (THD) is minimized. Predominately, these conduction angles for suppressing lower frequency harmonics of 5th, 7th, 11th, and 13th,… orders are eliminated in output [10] [24].

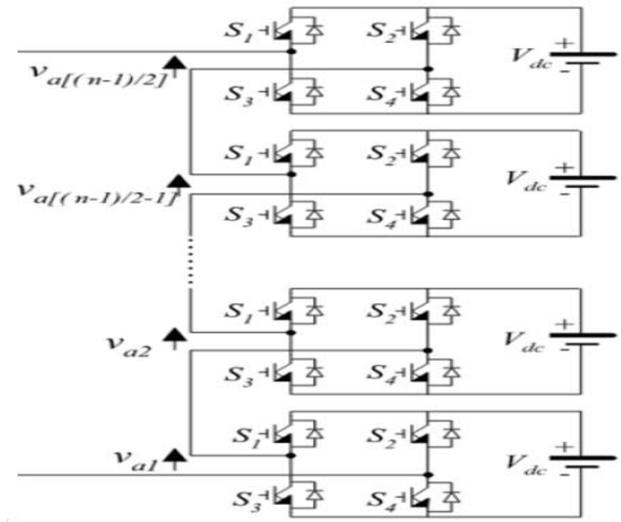


Fig. 1: Single leg of *n*-level cascaded H-bridge multilevel converter structure

IV. Predictive Direct Control Methods for PMSM

a) Predictive Current Control (PCC)

Predictive Current Control (PCC) uses only the predicted stator currents in the stationary reference frame in order to control the multiphase drive. Current references are obtained in the rotating reference frame from an outer PI speed control loop and a constant d-component current and then mapped in the stationary reference frame in order to be used in the cost function, as shown in Fig. 3.

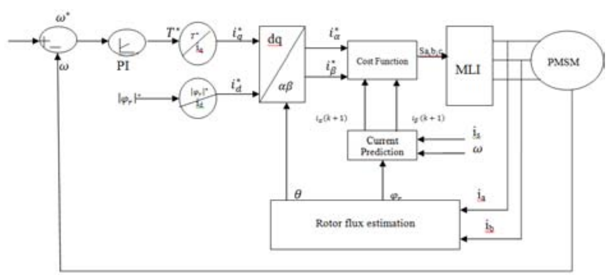


Fig. 2: Predictive Current Control using MPC

The aim is to generate a desired electric torque, which implies sinusoidal stator current references in a-b-c phase coordinates. In the stationary α-β-x-y reference frame, the control aim is traduced into a reference stator current vector in the α-β plane, which is constant in magnitude, but changing its electrical angle following a circular trajectory, and depending on the implemented multiphase machine, either null or non-null reference stator current vector in the x-y plane.

The PMSM model, stator current is as below:

$$i_s = -\frac{1}{R_\sigma}\left(\left(L_\sigma.\frac{di_s}{dt} - K_r.\left(\frac{1}{\tau_r} - j.\omega\right).\varphi_r\right) - u_s\right) \qquad [15]$$

where $K_r = \frac{L_m}{L_r}$, $R_\sigma = R_s + K_r^2.R_r$ and $L_\sigma = \sigma.L_s$

The forward Euler discretization is considered to predict the next step value as

$$\frac{dx}{dt} \cong \frac{x(k+1)-x(k)}{T_s} \qquad [16]$$

where T_s is the sampling time of the system.

Using (15) and (16), the stator current can be predicted as

$$\bar{\iota}_s(k+1) = \left(1 - \frac{T_s}{T_\sigma}\right).i_s(k) + \frac{T_s}{T_\sigma}.\frac{1}{R_\sigma}.\left[K_r.\left(\frac{1}{T_r} - j.\omega(k)\right).\varphi_r(k) + u_s(k)\right] \qquad [17]$$

where $T_\sigma = \sigma.\frac{L_s}{R_\sigma}$

The cost function is represented as below:

$$g_j = \sum_{h=1}^{N}\{|i_\alpha^* - i_\alpha(k+h)_j| + |i_\beta^* - i_\beta(k+h)_j|\} \quad [18]$$

The corresponding reference values for the field- and torque-producing currents i_d^* and i_q^* are produced by

$$i_d^* = \frac{|\varphi_r|^*}{L_m} \quad [19],$$

$$i_q^* = \frac{2}{3}\frac{L_r}{L_m}\frac{T^*}{|\varphi_r|^*} \quad [20]$$

In the cost function, the state's current values in $\alpha\beta$ frame are required. The inverse Park transformation is presented to satisfy this requirement as follows:

$$\begin{pmatrix}\alpha\\ \beta\end{pmatrix} = \begin{pmatrix}cos(\theta) & -sin(\theta)\\ sin(\theta) & cos(\theta)\end{pmatrix}\begin{pmatrix}d\\ q\end{pmatrix} \quad [21]$$

b) Predictive Torque Control (PTC)

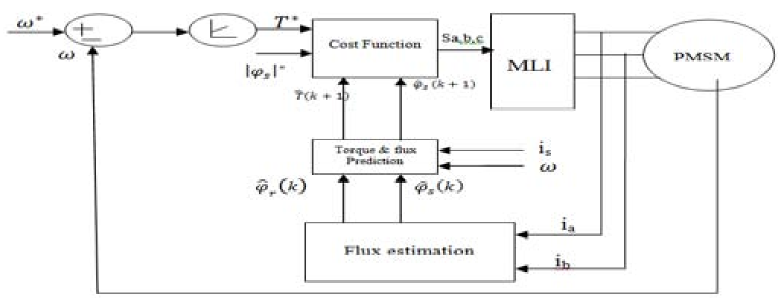


Fig. 4: Predictive Torque Control using MPC

Predictive Torque Control (PTC) based on FCS-MPC for three phase two-level induction motor drives given in [20] is shown in Fig. 4. It is done by an outer PI based speed control and an inner PTC and controlled variables are the stator flux and torque. Torque reference is provided by an external PI, based on the speed error, while the stator flux reference has been set at its nominal value for base speed operation. Then the cost function [10] [24] is evaluated and the switching state with a lower cost (J) is applied to the VSI. In order to improve PTC performance in [17] a modified cost function was presented, aimed to not only control stator flux and produced torque but also limit the maximum achievable α-β stator currents to ($i\alpha\beta{-}MAX$) and reducing harmonic components in the x-y plane.

The core aspects of PTC are the torque and flux predictions and the design of a cost function. In the predictive algorithm, the next-step stator flux ˆ $\psi s(k+1)$ and the electromagnetic torque ˆ $T(k+1)$ must be calculated. By using (9) to discretize the voltage model (1), the stator flux prediction can be obtained as

$$\bar{\varphi}_s(k+1) = \varphi_s(k) + T_s.u_s(k) - R_s.T_s.i_s(k) \quad [22]$$

The electromagnetic torque can be

$$\bar{T}(k+1) = \frac{3}{2}.p.Im\{\bar{\varphi}_s(k+1)^*.\bar{\imath}_s(k+1)\} \quad [23]$$

The classical cost function for the PTC method is

$$g_j = \sum_{h=1}^{N}\{|T^* - \bar{T}(k+1)_j| + \lambda.|\|\varphi_s^*\| - \|\bar{\varphi}_s(k+h)_j\||\} \quad [24]$$

V. Results

a) PCC and PTC method with PMSM and IM using 15- level inverter

PCC and PTC for a 4-pole induction machine have simulated with 15-level multilevel inverter and compared with 2-level voltage source inverter. The rating of induction motor is 5HP, 440V, 50Hz, 1440 RPM star connected induction motor. For all simulations, the motor characteristics will be utilized as below:

Table 1: Induction motor parameters

Stator Resistance (ohm)	= 1.403
Rotor Resistance (ohm)	= 1.395
Stator Self Inductance (H)	= 0.005839
Rotor Self Inductance (H)	= 0.005839
Mutual Inductance (H)	= 0.2037
No. of poles	= 4
Moment of Inertia (kg.m^2)	= 0.0005
Sampling time,	= 1 Sec

PCC and PTC for a 4-pole PMSM have simulated with 15-level multilevel inverter and compared with 2-level voltage source inverter. For all simulations, the motor characteristics will be utilized as below: The parameters of PMSM motor are given in Table II. For all simulations, the motor characteristics will be utilized as below:

Table 2: PMSM parameters

Stator phase resistance Rs (ohm)	= 4.3
Armature Inductance (H)	= 0.0001
Flux linkage established by magnets (U.s)	= 0.05
Voltage Constant (U_peak L-L / krpm)	= 18.138
Torque Constant (N.m / A_peak)	=0.15
Inertia, friction factor, pole pairs [J (kg.m ^ 2)]	=0.000183
Friction factor F (N.m.s)	= 0.001
Pole pairs p( )	=2
Initial conditions[wm(rad/s) thetam(deg) ia,ib(A)]	= [0,0, 0,0]
Sampling Time (Sec)	=1

The Matlab, Simulink model of PCC and PTC methods with PMSM using 15-level inverter shown in fig.3 and fig.4. To achieve a comparison between the two methods, the external PI speed controllers are configured with the same parameters. The results of the PCC method and the PTC method with PMSM using 15-level inverter is shown in fig.5, fig.6 compared with the simulation results of the PCC method and the PTC method with IM using 15-level inverter shown in Fig.7, Fig.8 [10] [24]. From the pictures, we can see that both methods have good and similar behaviors at this point in the operation. The PCC method has a slightly better current response; however, the torque ripples of the PTC method are lower than those of the PCC method. The performances in the whole speed range are investigated in the simulations. The motor rotates from positive nominal speed to negative nominal speed. During this dynamic process, the measured speed, the torque, and the stator current are observed. It is clear that both methods have very similar waveforms. They each have almost the same settling time to complete this reversal process due to the same external speed PI parameters. The torque ripples of the PTC method are slightly lower than those of the PCC method. From these simulations, we can conclude that two methods can work well in the whole speed range and have good behaviors with the full load at steady states.

Fig. 5: PCC with 15- MLI PMSM Result

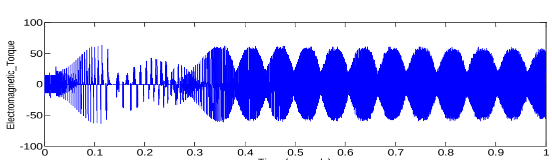


Fig. 5: (a) Electromagnetic torque in PCC

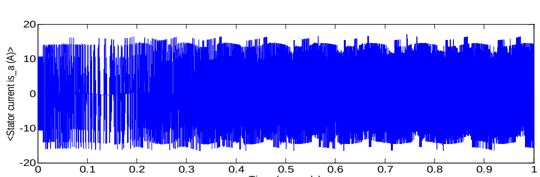


Fig. 5: (b) Stator current in PCC

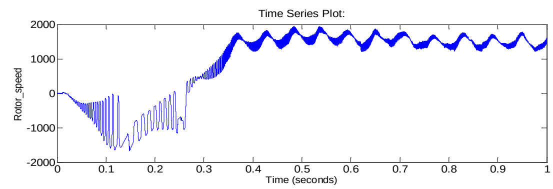


Fig. 5: (c) Rotor speed in PCC

Fig. 6: PTC with 15-MLI PMSM result

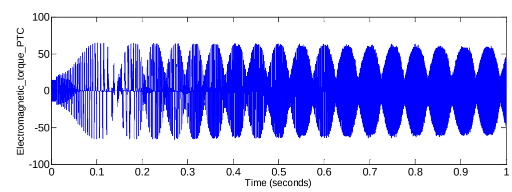


Fig. 6: (a) Electromagnetic torque in PTC

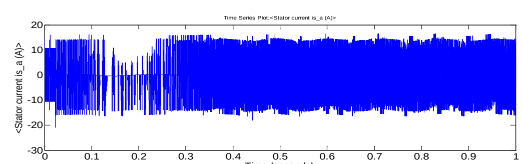


Fig. 6: (b) Stator current in PTC

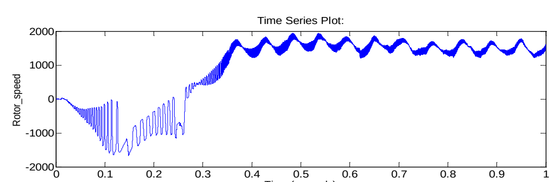


Fig. 6: (c) Rotor speed in PTC

Fig. 7: PCC with 15-level MLI using IM

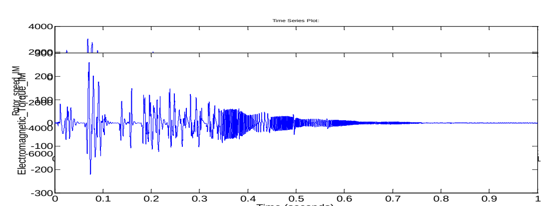


Fig. 7: (a) Rotor speed in PCC

Fig. 7: (b) Electromagnetic torque in PCC

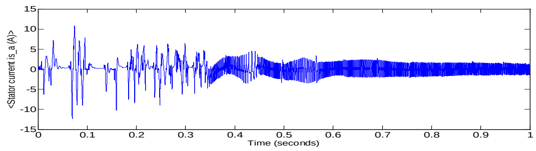


Fig. 7: (c) Stator current in PCC

Fig. 8: PTC with 15-level MLI using IM result

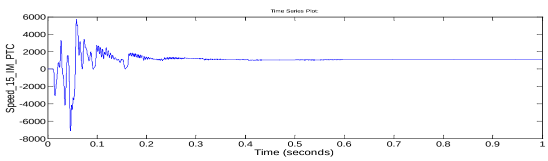


Fig. 8: (a) Rotor speed in PTC

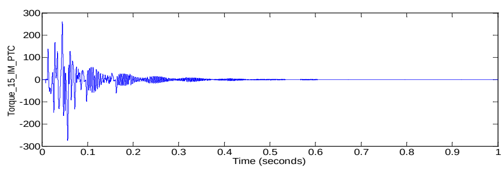


Fig. 8: (b) Electromagnetic torque in PTC

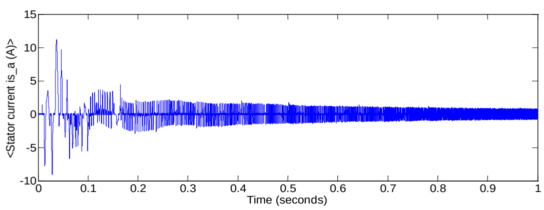


Fig. 8: (c) Stator current in PTC

Fig. 9: THD in PCC with 15-level MLI using PMSM result

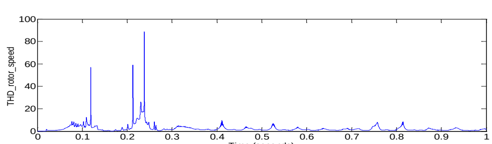


Fig. 9: (a) THD in rotor speed

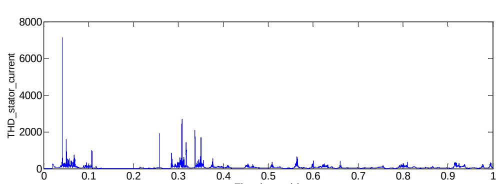


Fig. 9: (b) THD in stator current

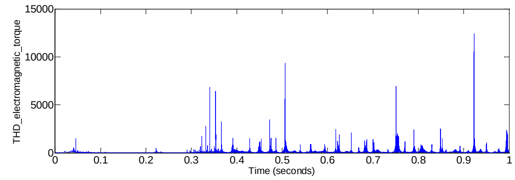


Fig. 9: (c) THD in Torque

Fig. 10: THD in PTC with 15- MLI using using PMSM

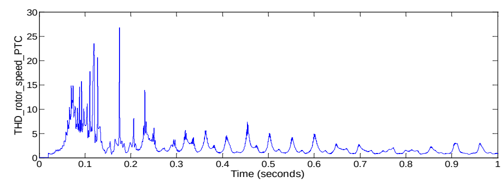


Fig. 10: (a) THD in rotor speed

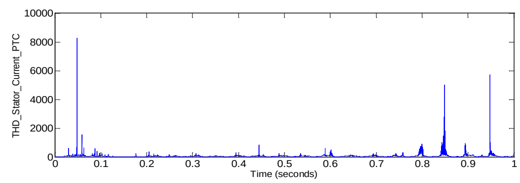


Fig. 10: (b) THD in stator current

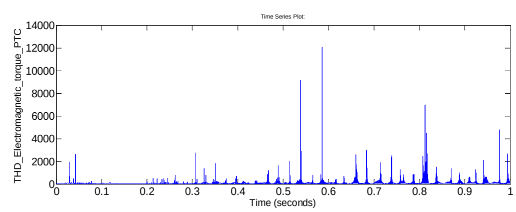


Fig. 10: (c) THD in Torque

Fig. 11: THD in PCC with 15-level MLI using IM

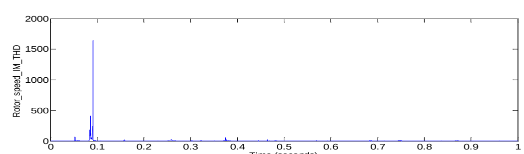


Fig. 11: (a) THD in Rotor speed

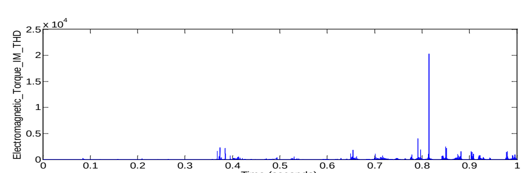


Fig. 11: (b) THD in Torque

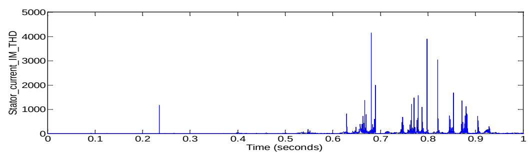


Fig. 11: (c) THD in stator current

Fig. 12: THD in PTC with 15- MLI using IM

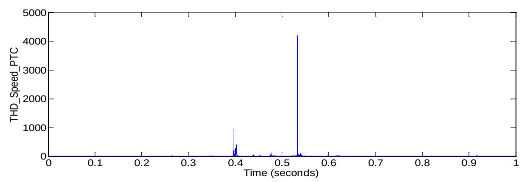


Fig. 12: (a) THD in rotor speed

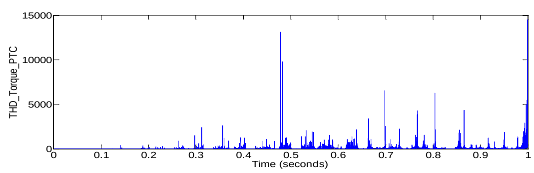


Fig. 12: (b) THD in Torque

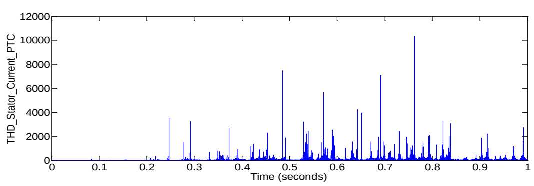


Fig. 12: (c) THD in stator Current

Fig. 13: PCC with 2-level VSI using PMSM

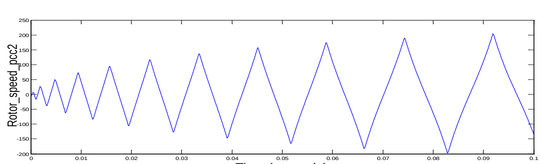


Fig. 13: (a) Rotor speed in PCC

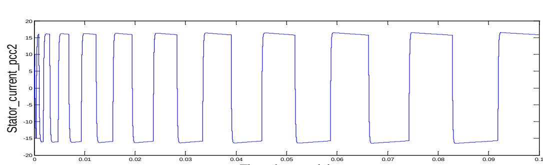


Fig. 13: (b) Stator current in PCC

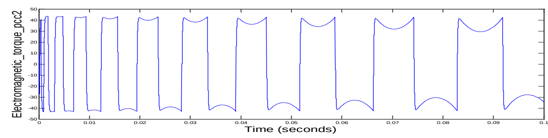


Fig. 13: (c) Obtained torque in PCC

Fig. 14: PTC with 2-level VSI using PMSM

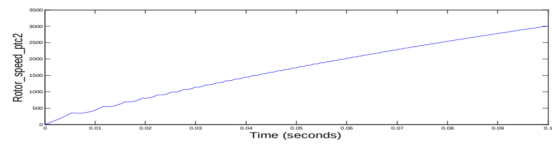


Fig. 14: (a) Rotor speed in PTC

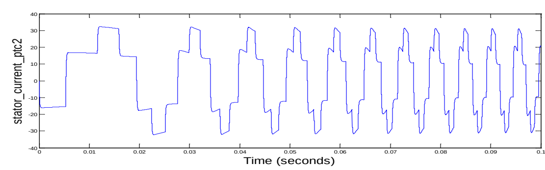


Fig. 14: (b) Stator current in PTC

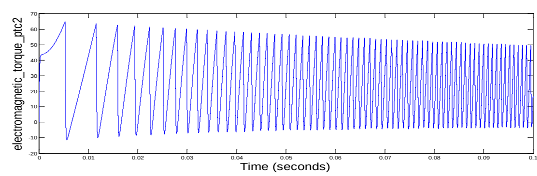


Fig. 14: (c) Obtained torque in PTC

Fig. 15: PCC with 2-level VSI using IM

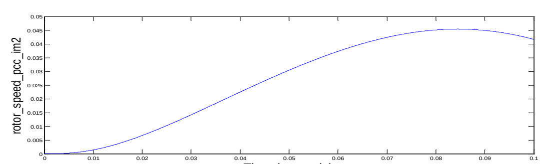


Fig. 15: (a) Rotor speed in PCC

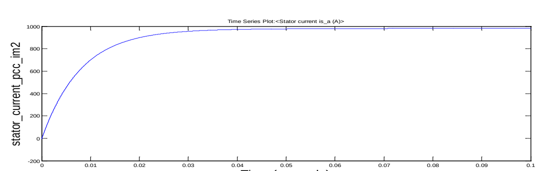


Fig. 15: (b) Stator current in PCC

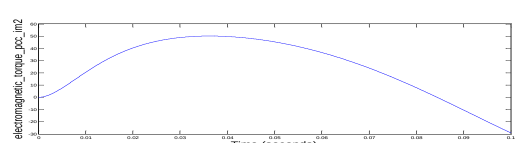


Fig. 15: (c) Obtained torque in PCC

Fig. 16: PTC with 2-level VSI using IM

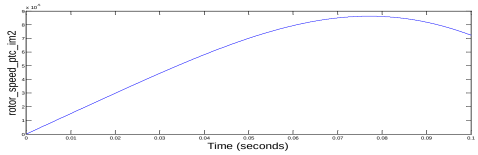


Fig. 16: (a) Rotor speed in PTC

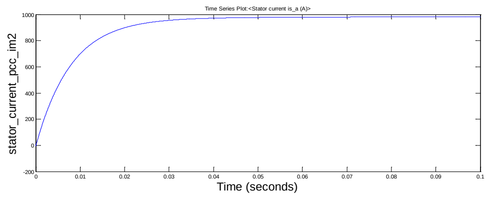


Fig. 16: (b) Stator current in PTC

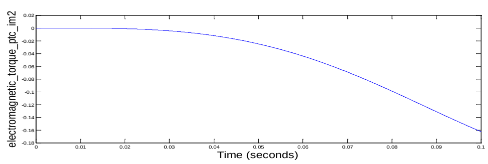


Fig. 16: (c) Obtained torque in PTC

Fig. 17: THD in PCC with 2-level VSI using PMSM

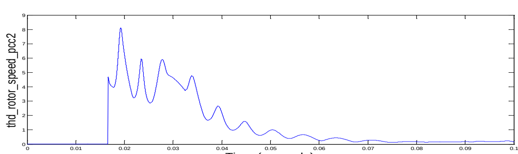


Fig. 17: (a) THD in rotor speed

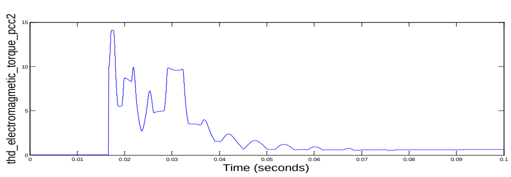


Fig.17: (b) THD in electromagnetic torque

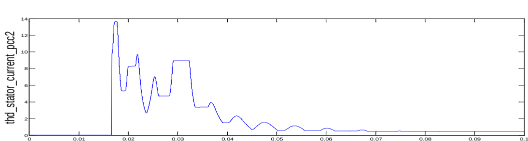


Fig.17: (c) THD in stator current

Fig. 18: THD in PTC with 2-level VSI using PMSM

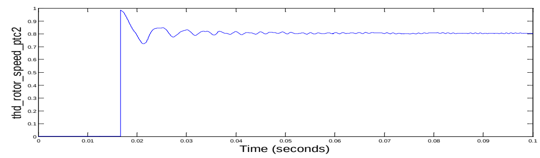


Fig. 18: THD in rotor speed

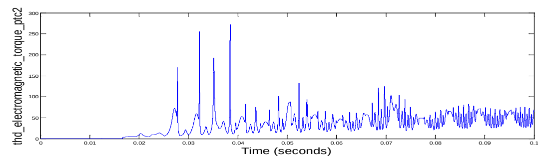


Fig. 18: (b) THD in electromagnetic torque

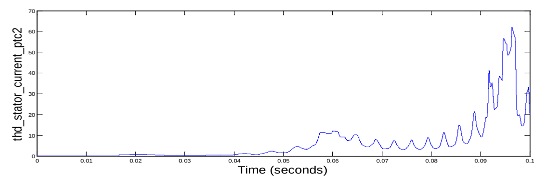


Fig. 18: (c) THD in stator current

Fig. 19: THD in PCC with 2-level VSI using IM

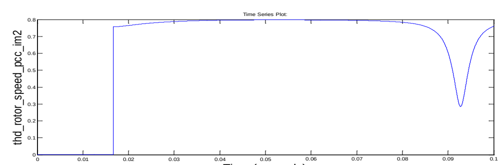


Fig. 19: (a) THD in rotor speed

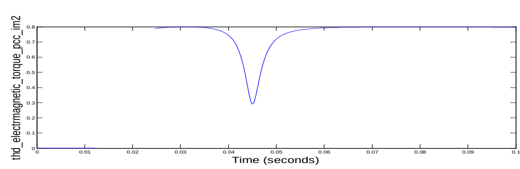


Fig. 19: (b) THD in electromagnetic torque

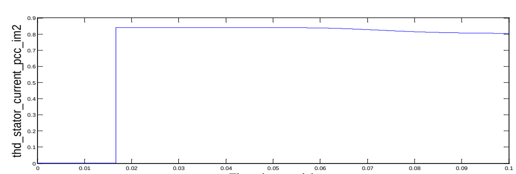


Fig. 19: (c) THD in stator current

Fig. 20: THD in PTC with 2-level VSI using IM

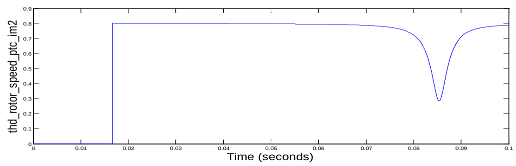


Fig. 20: (a) THD in rotor speed

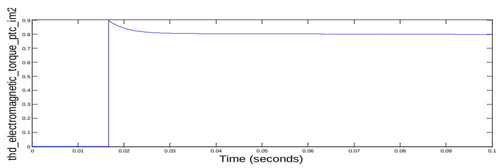


Fig. 20: (b) THD in electromagnetic torque

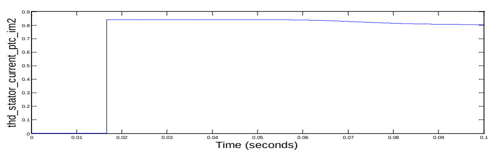


Fig. 20: (c) THD in stator current

Total harmonic distortion (THD) has calculated successfully in this article by using MATLAB 2013. The proposed scheme shows better response as compared to the conventional one in terms of Total Harmonic Distortion (THD) in speed, torque, and stator current during transient conditions. Fig. 5 (a), (b), (c) and Fig.6 (a), (b), (c) represent the corresponding speed, torque and stator current response of the PTC and PCC schemes using PMSM with a 15-level inverter. The THD in speed, electromagnetic torque and stator current in the PCC and PTC using PMSM with 15-level inverter is shown in Fig.9(a),(b),(c) and Fig.10 (a), (b), (c) respectively. Similarly Fig. 7(a), (b), (c) and Fig.8 (a), (b), (c) represent the corresponding speed, torque and stator current response of the PTC and PCC schemes with a 15-level inverter using IM. The THD in speed, electromagnetic torque and stator current in the PCC and PTC method with IM using 15-level inverter is shown in Fig.11(a), (b), (c) and Fig.12 (a), (b), (c) respectively. It can be compared that, the THD in speed, torque, and stator current with PCC is approximately 5.3% reduces while with PTC is approximately 4.8% reduces in the conventional scheme as per article [10]. In the proposed scheme with 15-level inverter, the THD in speed, torque and stator current with PCC is approximately 23% reduces while, with PTC is approximately also 23 % reduces, which proves the superiority of the proposed PCC and PTC scheme with 15-level inverter over the conventional one compare to article [10] [23] [24]shown in Table.3.

b) PCC and PTC method with PMSM and IM using 2- level inverter

The Matlab, Simulink model of PCC and PTC methods with PMSM using 2-level inverter shown in fig.3 and fig.4. To achieve a comparison between the two methods, the external PI speed controllers are configured with the same parameters. The simulation results of the PCC method and the PTC method with PMSM using 2-level inverter is shown in fig.13(a),(b),(c) and fig.14 (a),(b),(c) compared with the simulation results of the PCC method and the PTC method with IM using 2-level inverter shown in Fig.15 (a),(b),(c), Fig.16 (a),(b),(c) respectively [10] [24]. The PCC method has a slightly better current response; however, the torque ripples of the PTC method are lower than those of the PCC method. The performances in the whole speed range are investigated in the simulations. The motor rotates from positive nominal speed to negative nominal speed. During this dynamic process, the measured speed, the torque, and the stator current are observed. It is clear that both methods have very similar waveforms. They each have almost the same settling time to complete this reversal process due to the same external speed PI parameters. The torque ripples of the PTC method are slightly lower than those of the PCC method. From these simulations, we can conclude that two methods can work well in the whole speed range and have good behaviors with the full load at steady states.

Total harmonic distortion (THD) has calculated successfully in this article by using MATLAB 2013. The proposed scheme shows better response as compared to the conventional one in terms of Total Harmonic Distortion (THD) in speed, torque, and stator current during transient conditions. Fig. 13 (a), (b), (c) and Fig.14 (a), (b), (c) represent the corresponding speed, torque and stator current response of the PTC and PCC schemes using PMSM with a 2-level inverter. The THD in speed, electromagnetic torque and stator current in the PCC and PTC using PMSM with 2-level inverter is shown in Fig.17(a),(b),(c) and Fig.18 (a), (b), (c) respectively. Similarly Fig. 15(a), (b), (c) and Fig.16 (a), (b), (c) represent the corresponding speed, torque and stator current response of the PTC and PCC schemes using IM with a 2-level inverter. The THD in speed, electromagnetic torque and stator current in the PCC and PTC method a 2-level inverter is shown in Fig.19(a), (b), (c) and Fig.20 (a), (b), (c) respectively. It can be compared that, the THD in speed, torque, and stator current with PCC is approximately 5.3% reduces while with PTC is approximately 4.8% reduces in the conventional scheme as per article [10] [24]. In the proposed scheme with 2-level inverter, the THD in speed, torque and stator current with PCC is approximately 19% reduces while, with PTC is approximately also 36 % reduces, which proves the superiority of the proposed PCC and PTC scheme with 2-level inverter over the conventional one compare to article [10] [23] shown in Table. 2.

Both the PTC and PCC methods are most useful direct control methods with PMSM method gives 10% to 30% more torque than an induction motor also not require modulator [3]. Induction motor work on only lagging power factor means it can produce only 70-90% of torque produced by PMSM with same current. Total harmonic distortion (THD) has calculated successfully in this article by using MATLAB 2013 compare to [10] [24]. The PCC and PTC method with 15-level H-bridge multilevel inverter using PMSM reduces 23% more THD in torque, speed and stator current compared to PCC and PTC method with 15-level H-bridge multilevel inverter using an induction motor shown detail in Table.3 [21]. The graphical representation of % THD in rotor speed, electromagnetic torque and stator current also shown in graph-1,2,3. The comparative issues between PCC and PTC also shown in Table.4.

c) THD Analysis of PCC and PTC Method

Table 3: %THD Calculation comparison

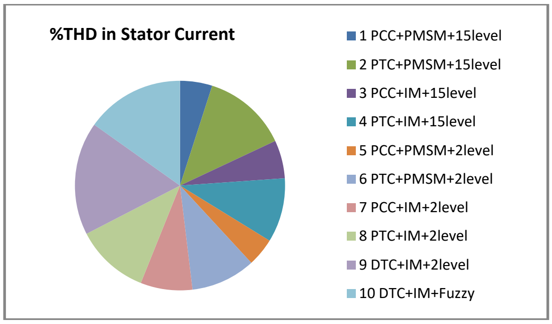
Sr. No.	Different Methods	%THD in		
		Rotor Speed (w_r)	Torque (T_e)	Stator Current
1	PCC with PMSM using 15-level multilevel inverter	31.44	31.34	44.85
2	PTC with PMSM using 15-level multilevel inverter	21	21	118
3	PCC with IM using 15-level multilevel inverter	54.24	155.2	53.22
4	PTC with IM using 15-level multilevel inverter	41.51	41.51	89.67
5	PCC with PMSM using 2-level voltage source inverter(VSI)	82.45	68.60	39.39
6	PTC with PMSM using 2-level voltage source inverter(VSI)	106.11	41.40	90.02
7	PCC with IM using 2-level voltage source inverter(VSI)	118.86	98.14	72.21
8	PTC with IM using 2-level voltage source inverter(VSI)	57.20	79.38	102.34
9	Direct Torque control of IM using 2-level voltage source inverter(VSI)	49.53	81.62	157.84
10	Direct Torque control of IM with Fuzzy Logic Controller using 2-level voltage source inverter(VSI)	49.53	61.82	137.14

d) Comparative Issues between PCC and PTC

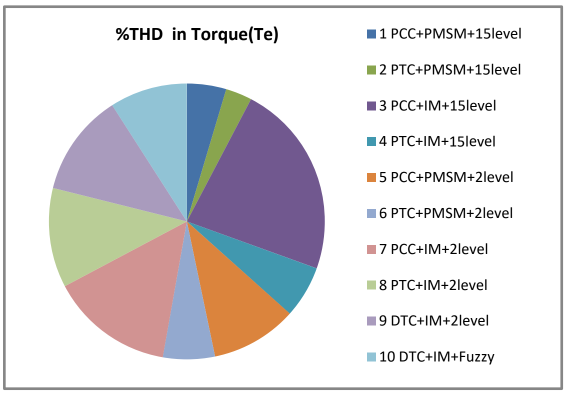
Table. 4: Comparative issues between PCC and PTC

Feature	PCC	PTC
Conceptual Complexity	Low	Low
PI-current controller	No	No
Use of PWM	No	No
Switching Frequency	Variable	Variable
Dynamics	Fast	Fast
Torque Ripple	Higher	Lower
Stator current THD	Lower	Higher
System Constraints Inclusion	Easy	Easy

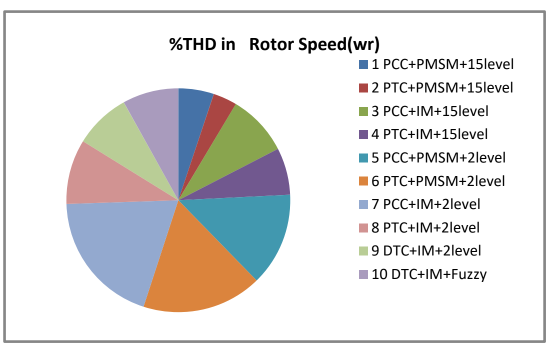
e) Graphical Representation of % THD in Speed, Torque and Stator Current



a. Graph-1: % THD in Stator Current



b. Graph-2: % THD in Torque



c. Graph-3: % THD in rotor speed

VI. Conclusion

In this paper, PCC and PTC methods of MPC family with 15-level multilevel inverter have been presented and discussed by simulation method only. PCC and PTC methods with 15-level multilevel inverter are direct control methods without an inner current PI controller or a modulator, the PCC method with 15-level multilevel inverter has lower calculation time than the PTC method with 15-level multilevel inverter, fast dynamic response, and Lower stator current harmonics than PTC. This advantage makes the PCC method more accurate for applications with longer prediction horizons. From the test results, it is clear that the PCC method and the PTC method with 15-level multilevel inverter have very good and similar performances in both steady and transient states. PTC method with 15-level multilevel inverter has lower torque ripples; however, the PCC method with 15-level multilevel inverter is better when the currents are evaluated. This novel method attracted the researchers very quickly due to its straightforward algorithm and good performances both in steady and transient states. Future work is to test switched reluctance motor, and servo motor with multilevel inverter is applied to PCC and PTC method, we can imagine that the PCC algorithm and PCC algorithm will greatly reduce the calculation time. The PCC method shows strong robustness with respect to the stator resistance; however, the PTC method shows much better robustness with respect to the magnetizing inductance.

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An Innovative Zero-Emission Energy Model for a Coastal Village in Southern Myanmar

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Abstract- Myanmar boosts the Renewables harvesting with On-Grid and Off-Grid options to implement 2030 Agenda. Reversing the degradation of the Coastal Eco-System is also the prioritized Agenda. The research and deployment of Photovoltaic (PV), Wind, and Hybrid Mini-Grids are at the initial state and separated. This work imagined for supporting and bridging these. Thus, a village Lel Hpet, located in Palaw Township, Tanintharyi Region chose due to its blessings of PV and Wind resources. The villagers currently use the Diesel Generators for the industrial loads and the fuelwood for the cooking. These cause the negative impacts. Hence, Zero-Emission Energy Model analyzed. The total demand separated into Primary and Deferrable Loads. The simulation innovated with four Models on the excellent platform for Energy Planning, HOMER (Hybrid Optimization of Multiple Energy Resources) Pro (version 3.11.5). Then, the Best Model is selected.

Keywords: southern Myanmar, Tanintharyi coast, village lel hpet, HOMER Pro, zero-emission energy model, simulation, standalone PV-wind-battery hybrid mini-grid.

GJRE-F Classification: FOR Code: 090699

ANINNOVATIVEZEROEMISSIONENERGYMODELFORACOASTALVILLAGEINSOUTHERNMYANMAR

Strictly as per the compliance and regulations of:

An Innovative Zero-Emission Energy Model for a Coastal Village in Southern Myanmar

Aung Ze Ya

Abstract- Myanmar boosts the Renewables harvesting with On-Grid and Off-Grid options to implement 2030 Agenda. Reversing the degradation of the Coastal Eco-System is also the prioritized Agenda. The research and deployment of Photovoltaic (PV), Wind, and Hybrid Mini-Grids are at the initial state and separated. This work imagined for supporting and bridging these. Thus, a village Lel Hpet, located in Palaw Township, Tanintharyi Region chose due to its blessings of PV and Wind resources. The villagers currently use the Diesel Generators for the industrial loads and the fuelwood for the cooking. These cause the negative impacts. Hence, Zero-Emission Energy Model analyzed. The total demand separated into Primary and Deferrable Loads. The simulation innovated with four Models on the excellent platform for Energy Planning, HOMER (Hybrid Optimization of Multiple Energy Resources) Pro (version 3.11.5). Then, the Best Model is selected. Its simulative results proved Wind is more feasible than PV on the Tanintharyi Coast, PV and Wind can compensate each other during their less generation months, and the larger Off-Grid Mini-gird is more cost-effective. The savings of the Diesel fuel usage and its costs, and the reduction of GHG (greenhouse gas) Emissions predicted. The proposed Climate-friendly, standalone PV-Wind-Battery Hybrid Mini-Grid can improves the Green penetration in Southern Myanmar.

Keywords- southern Myanmar, Tanintharyi coast, village lel hpet, HOMER Pro, zero-emission energy model, simulation, standalone PV-wind-battery hybrid mini-grid.

I. Introduction

Myanmar, 40th largest nation in the world, geographically located between 9º 32' and 28º 31' N latitude; and 92º 10' and 101º 11' E. It situated as the strategic link of South Asia and South East Asia. It covers a land area of over 676,577 square kilometers and stretches over 2280 kilometers [3].

a) Myanmar's Three Coasts

Myanmar is very susceptible to extreme weather risks, landslides, sea-level rise related to air-current, and predicted future climate change. Coastal erosion and flooding are further risks which are predicted to grow. Tropical storms, occasional cyclones suffer regularly. The coastline is nearly 3000 km, extending about 1900 km from 10° to 21° North of the Equator, and 93° to 97° East of Greenwich [4].

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Fig. 1 shows Myanmar's three Coasts, Rakhine Coast, Ayeyarwady Delta Coast, and Tanintharyi Coast. Mayu and Kaladan rivers flow into the Rakhine Coast. Ayeyarwady, Sittaung and Thanlwin rivers flow into Ayeyarwady Delta Coast, and Ye, Dawai, Tanintharyi, Lenya rivers flow into the Tanintharyi Coast [3].

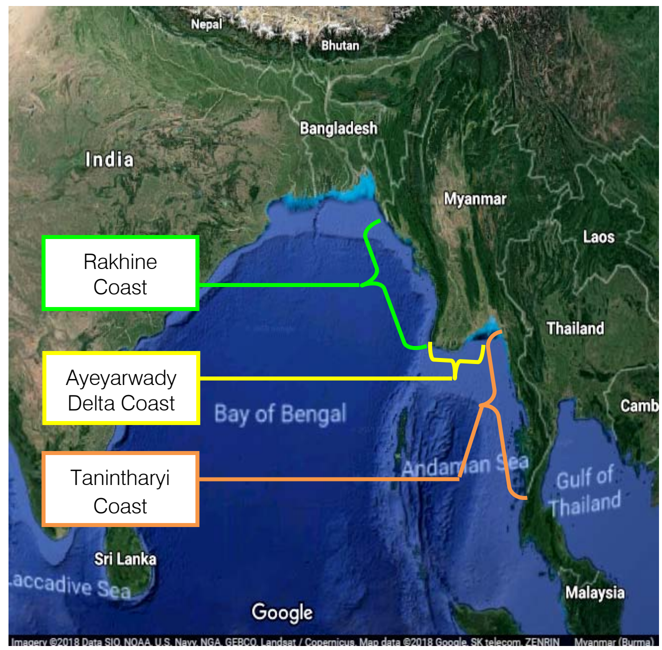

Fig. 1: Myanmar's Three Coasts [6]

Tanintharyi Coast is the longest among three. It bounded by the Andaman Sea in the West. It scopes South of the Gulf of Mottama up to the mouth of Pakchan River. It also included Myeik Archipelago, and Andaman Sea [3]. The Coasts are abundant with the coral reefs, mangroves, seagrass beds, mudflats, estuaries, and the dunes. These all play the role to uplift the quality of life of local community, and the environmental diversity. Also, these are paramount for the development of the agricultural, forestry, fishery and the tourism sectors [5].

Unsustainable development can exacerbate the rural poverty in the coastal areas, and cause to leave the native villagers and weaken the majority of the population. Consequently, the rural population is behind the urban populations grow and prosper. Rural poverty remains the problem, and in the context of rising sea levels, and increasingly unstable weather. Coastal resilience is an issue of ever growing importance [4].

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b) Standalone Mini-Grids in Myanmar

National Electrification Planning (NEP) of Myanmar Agenda 2030 aimed to electrify 7.2 million households, and achieve universal access to electricity by 2030. In the long term, the least cost extension of the National Grid System (NGS) included. For pre-electrification, the standalone Mini-Grids and Solar Home Systems (SHS) are the options for the rural areas far from that National Grid will take many years to reach [13]. The criteria to implement the standalone Mini-Grid are the village can't electrify by the NGS in the next five to ten years, its location is at least 10 kilometers from the NGS, the sufficient demand for Mini-Grid scale, and the number of households should be 150 to 200 with the concentrated group. Large villages with high demands are preferable as a high possibility of the stronger revenue streams to achieve Sustainable Mini-Grids [9].

c) Motivation

The motivation of this work is to energize the village with the Innovative Hybrid System to conserve the Coastal Eco-System. Also, it targeted to promote the Rural Electrification rate by improving the Green Growth.

d) Hierarchical Methodology

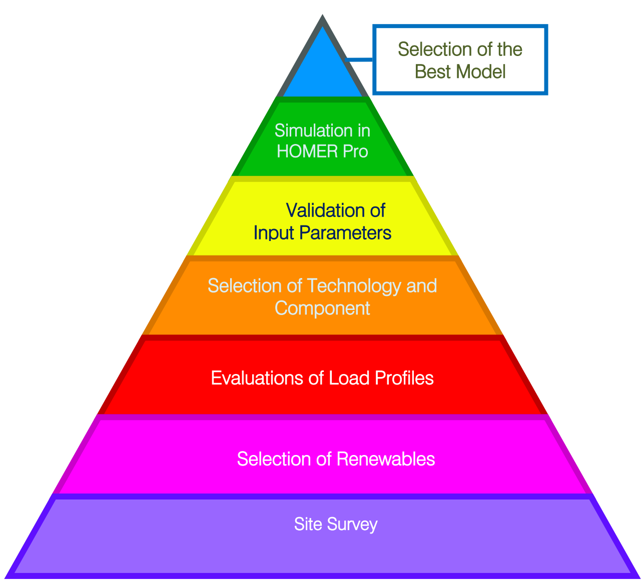


Fig. 2: The Pyramid of the Hierarchical Methodology

The hierarchical methodology is comprehensive process that involved the seven steps depicted as the pyramid in Fig. 2. The site survey is the fountain and essential work to know the real ground situation. The problems of the existing Energy access identified. Then, the appropriate Energies selected due to the potentials of the site and the priorities of the country. As the third step, the relevant technology and components chose. The load profiles predicted. The input parameters validated as the fifth step. The principal work is the Techno-Economic Optimizations of different models performed in the well-proven tool, HOMER Pro (version 3.11.5). The final step is the selection of the Best Model.

e) Identification of the Problems

The inhabitants are commonly using the small Diesel Generators for the water pumping and the industrial loads. All the houses apply the Compact Fluorescent Lamps (CFL) for the lightings and the fuelwood for the cookings. The identified problems are:

1) Contribution to the Global Warming due to the GHG Emissions from the burning of the Diesel fuels and the fuelwood [15-18],
2) Deforestation and Climate Change from the application of the fuelwood for the cooking,
3) Degradation of the bio-diverse eco-systems in the Coastal Region,
4) Health problems from the burning of the Diesel fuels and the fuelwood [20-22],
5) Easy to be fire hazards from the applications of the Diesel Generators and the firewood,
6) Insufficient and the limited supply from the existing SHS and the Diesel Generators, and
7) Environmental (Negative) impacts from the usages of the Fluorescent Lamps [19-21].

II. Zero-Emission Energy (Standalone PV-Wind- Battery Hybrid) Model in HOMER Pro

To solve above problems, the Standalone PVWind-Battery Hybrid Mini-Grid modeled in HOMER Pro.

a) Project Location in Tanintharyi Coast

Fig. 3 mentions the project location in the map-box of HOMER Pro. The village Lel Hpet in Tanintharyi Coast placed according to its geographical coordinates (13.10019806ºN and 98.60114288ºE). Also, Time Zone adjusted due to Myanmar Standard Time: six hours and thirty minutes ahead of GMT (Greenwich Mean Time).

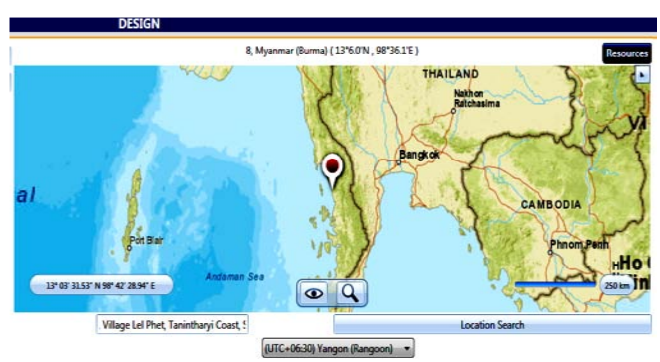


Fig. 3: Project Location (Village Lel Hpet)

b) Selection and Inputs of the Resources

Due to the geographical location, Myanmar has a rich Solar potential, and 60% of the land area appears suitable for PV deployments [10]. Fig. 4 [11] illustrates GHI (Global Horizon Irradiation) of Myanmar. From it, it is clear that the project location has the potential of Solar PV Energy. There are a few months (June, July, and August), which cannot favor for the PV generation. Hence, PV Energy is firstly selected to harvest.

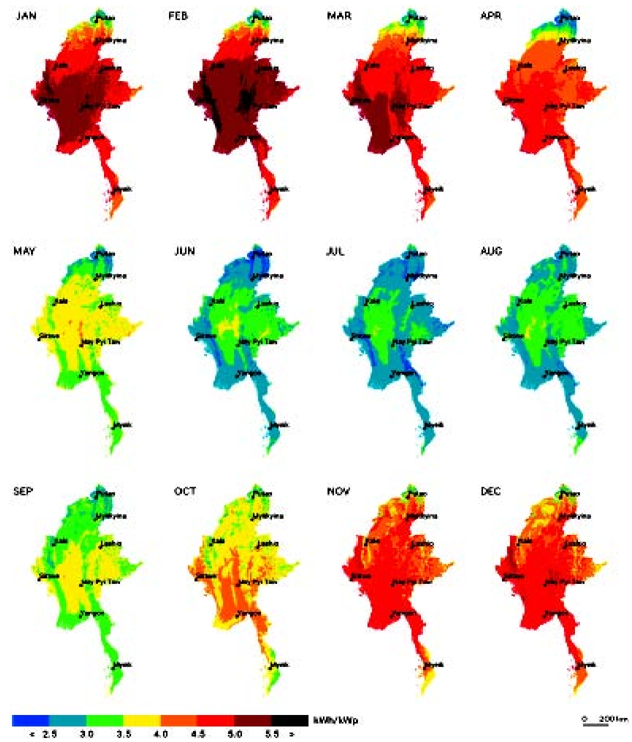


Fig. 4: GHI of Myanmar [11]

Fig. 5: GHI of a Village Lel Hpet

The input resources data of GHI downloaded from NREL (National Renewable Energy Lab) database in HOMER Pro highlighted in Fig. 5. Also, the required temperature data and Wind resources data downloaded from NREL in HOMER Pro.

According to the research of New Energy and Industrial Technology Development Organization (NEDO) in 1997, Myanmar has the strong potential of Wind Energy, with an estimated potential of 365 terawatt-hours (TWh) per year, especially abundant in the Chin and Shan states, and along the Coast [14]. Therefore, Wind Energy selected for the proposed project. To conserve the Eco-System of the Coast, and to protect from the Social Impacts, Hydropower did not consider in this study.

The strong winds can damage not only PV modules but also the construction components. However, the positive impacts can cause the low and medium speed winds. These winds create the cooling effects on PV modules and increase the power generation [11]. Hence, the Wind potential showed in Fig. 6 is not high, but, it can be beneficial for PV system. In June, July, and August, Wind has the high potentials. Thus, Wind System can compensate the less generation of PV System in these months. This point is the advantage of PV-Wind Hybrid System.

Fig. 6: Wind Resources Data of a Village Lel Hpet

c) Load Profiles

The Eco-friendly and the Energy Efficient loads are considered. To apply the effective simulation-features of HOMER Pro, the total demand divided into two main types, Primary Load (PL) and Deferrable Load (DL) as depicted in Fig.7.

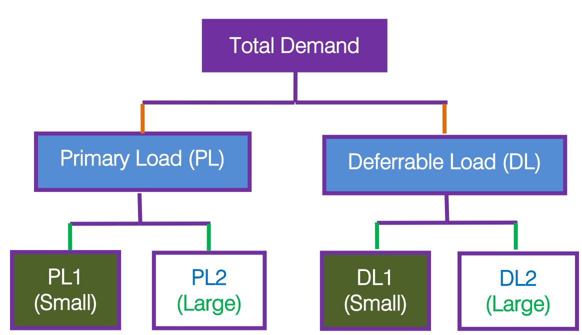


Fig. 7: The Composition of the Total Demand

PL is sub-divided into two types. PL1 (small) includes the LED lamps, flat TVs, and other small loads. PL2 (large) consists of the kitchen loads (the rice-cookers, the cooking pots), the cooling loads (the fans, the air-coolers, and the water-coolers) and the small industrial loads listed in Table 1. DL composed of two categories. DL1 (small) contains the mobile chargers, the power banks, and the rechargeable LEDs. DL2 (large) involves the fifteen 1.5 kW water pumping loads.

Table 1: Small Industrial Loads of PL2 and DL2

Load Type	Description	Power (kW)	Amount
PL2	Carpentry Workshop	1000	8
	Cold Storage	140	20
DL2	Water Pumping	1500	15

Based on the collected data from a site visit in January 2018, the load profiles predicted for a one Pagoda, a one Monastery, 250 households (HH), and the school, the street lightings, the water pumping loads, and the small industrial loads. The households (HH) are classified as the three groups depending on the demands. The low and high demand groups have 25 and 50 households. The medium demand group has 175 households. Table 2 listed the total demands of each HH group. Figs.8 to 10 described the inputs of the Primary Loads (PL1, PL2) and Deferrable Load (DL).

Table 2: Total Demands of Each HH Group

Group	Primary Load 1 (kilowatt, kW)	Primary Load 2 (kW)	Small Deferrable Loads (kilowatt hour, kWh)
Low	1.320	22.5	1.305
Medium	13.833	192.5	13.020
High	11.600	60	4.350

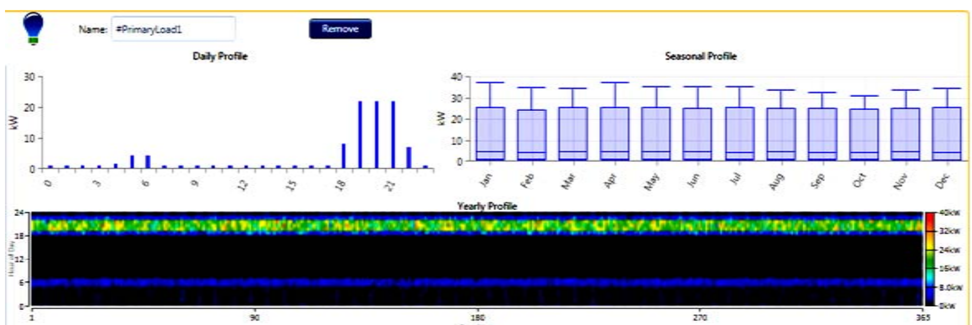


Fig. 8: PL1 Input in HOMER Pro

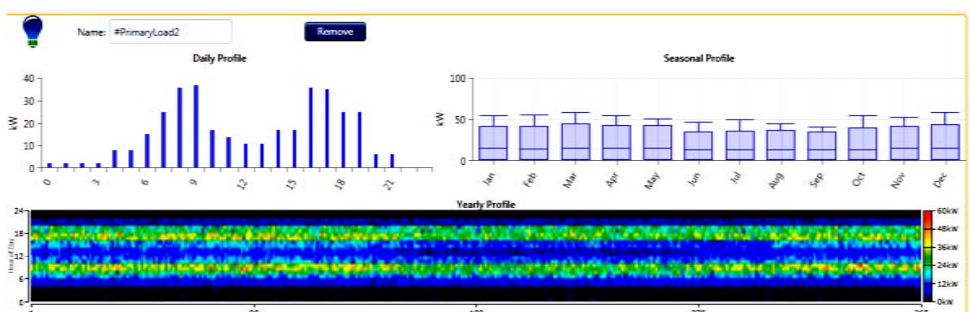


Fig. 9: PL2 Input in HOMER Pro

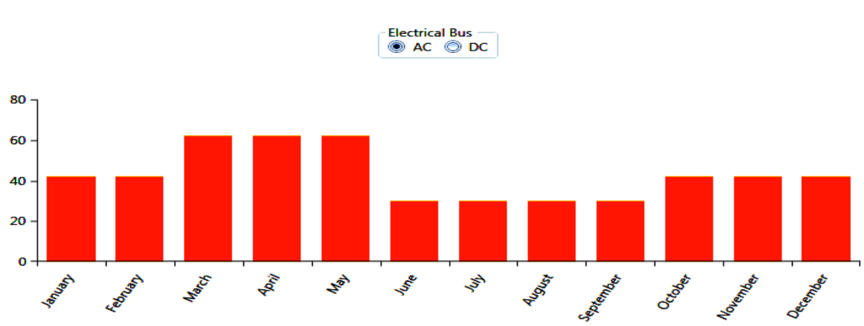


Fig.10: DL Input in HOMER Pro

d) Different Models in HOMER Pro

The modeling and the simulation are innovative. The different Models analyzed in HOMER Pro as shown in Table 3. HOMER performs the energy balance predictions, and then determines the feasible configurations to meet the demands under the specified conditions [1].

Table 3: Different Models

Model	Components	Demands
Model1 (M1)	PV-Wind-Battery Hybrid	PL1 and DL
Model2 (M2)	PV-Wind-Battery Hybrid	PL1 and PL2
Model3 (M3)	PV-Wind-Battery Hybrid	PL1, PL2,and DL
Model4 (M4)	Diesel Generators (50 kW & 25 kW)	PL1, PL2,and DL

The four Off-Grid Models explored in Figs.11 to 14. Models 1 to 3 investigated to know how the influence of the demands on the technological designs, and the economical aspects. Thus, their generating, the storage, and the converting components are the same with the different demand scenarios. Single-phase, 20 kW Wind Turbine is connected to AC (Alternating Current) Bus. The DC (Direct Current) outputs of the PV Arrays are stored into the Battery, and then converted into AC. All loads are connected to the AC Bus.

All demands (PL1, PL2 and DL) connected in the M3 and M4. PL1 is 108.6 kWh per day and 37.34 kW peak. PL2 is 336.14 kWh per day and 59.28 kW peak. Deferrable Load is 43 kWh per day and 28.75 kW peak.

Globally, the largest amount of GHG is significantly emitted from the fossil fuels utilizations for Electricity Generations [23]. Hence, the notable point is Diesel Mini-Grid (M4) modeled with the same demands as M3 to determine the specific amount of GHG Emissions, also, the fuel usage and the fuel cost from it.

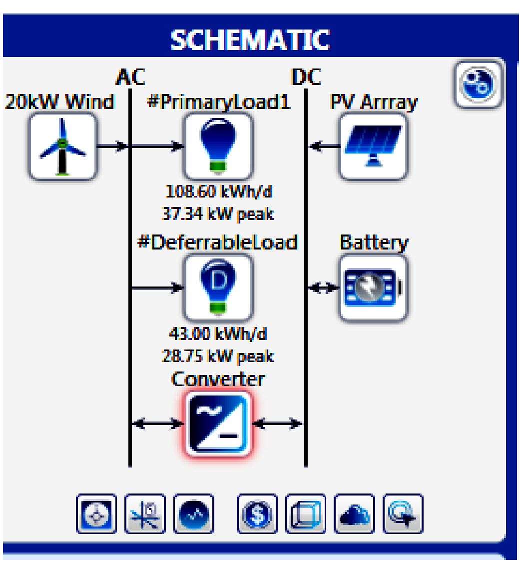


Fig.11: M1

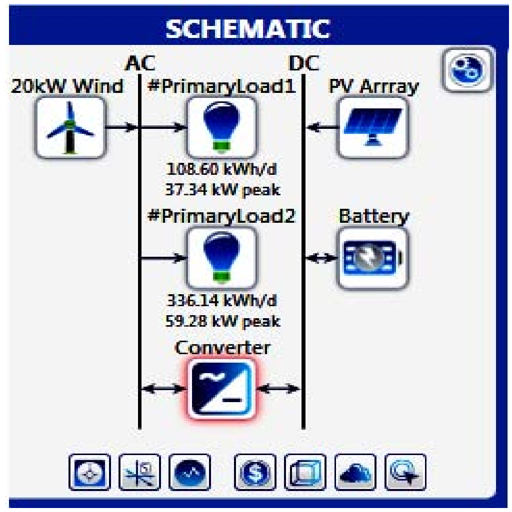


Fig. 12: M2

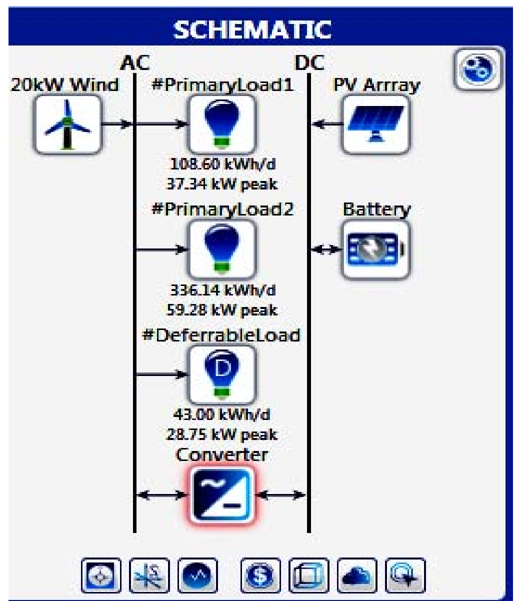


Fig. 13: M3

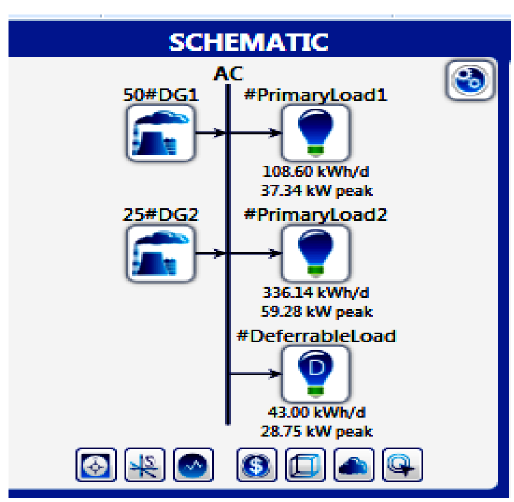


Fig. 14: M4

e) Economics, Constraints and Sensitivity Values

The Economics and the Constraints are the key parameters for the optimization, as well as the Energy Planning. From [7, 8], the nominal discount rate and the expected inflation rate set with the sensitivity values for the analysis. The other parameters also inputted in the Economics menu box of HOMER Pro as shown in Fig. 15. It is needed to change the System fixed capital cost, and System fixed O&M cost for the other models.

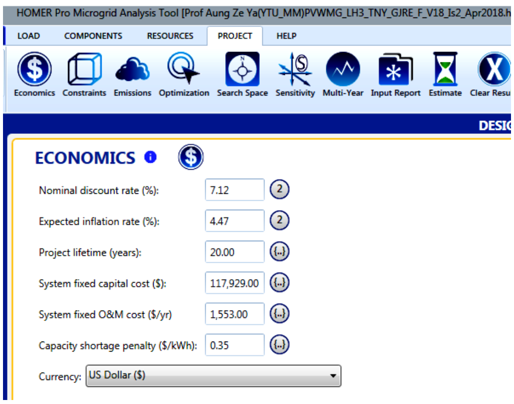


Fig.15: Economics Parameters of M3

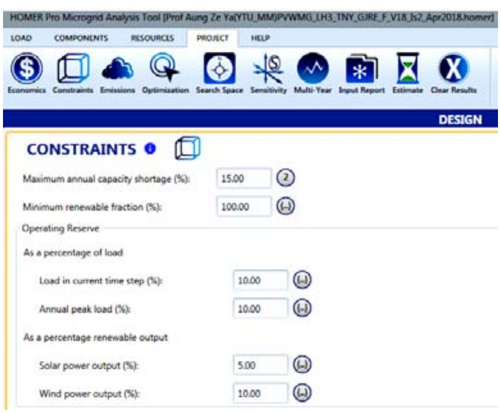


Fig.16: Constraints of M1 to M3

Fig. 16 explores the parameters of the Constraints of M1 to M3. Also, it required to the relevant change of the Constraints setting of the M4.

f) Inputs of Main Components

The parameters of the main components of the standalone PV Mini-grid modeled in HOMER Pro.

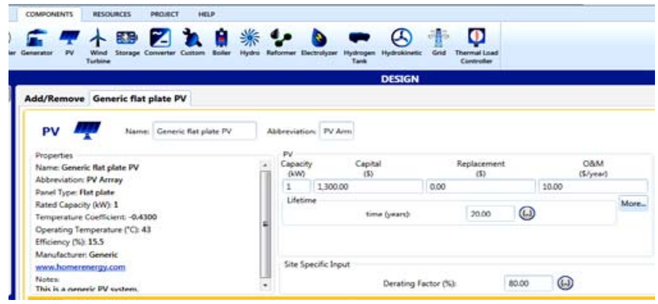


Fig.17: Inputs of PV System in HOMER Pro (M1 to M3)

The costs of PV for 1 kW are: Capital cost 1300 \$; Replacement cost 0 \$; Operation and maintenance cost 10 S/year, and lifetime 20 years. The advanced input is the ground reflectance 20%, and the array (panel) slope is 20.92°. Temperature inputs also set with PV Array temperature coefficient (%/°C) -0.43, and PV Array operating cell temperatures 43; and efficiency of the standard test condition is 15.5% as reflected in Fig. 17. The battery inputs for 1 kWh are: Capital cost 360 \$; Replacement cost 300 \$; Operation and maintenance cost 20 S/year; lifetime ten years. The converter inputs are: for 1 kW are: Capital cost 500 \$; Replacement cost 450 \$; Operation and maintenance cost 10 S/year and lifetime fifteen years. The costs of 20 kW Wind Generator is: Capital cost 14500 \$; Replacement cost 0 \$; Operation and maintenance cost 400 S/year, and the lifetime 20 years. It can easily imagine that the input components of Renewables are high-quality products due to their high costs.

For Diesel Mini-Grid (Model4, M4), 50 kW Diesel Generator costs are: Capital cost 10000 \$; Replacement cost 8000 \$; Operation and maintenance cost 1.5 \$ per hour; and the lifetime 15000 hours as shown in Fig.18. The Diesel fuel price inputted 0.62 and 0.72 \$/L. 25 kW Diesel Generator costs are: Capital cost 4500\$; Replacement cost 4000 \$; Operation and maintenance cost 0.75 \$ per hour; and the lifetime 15000 hours.

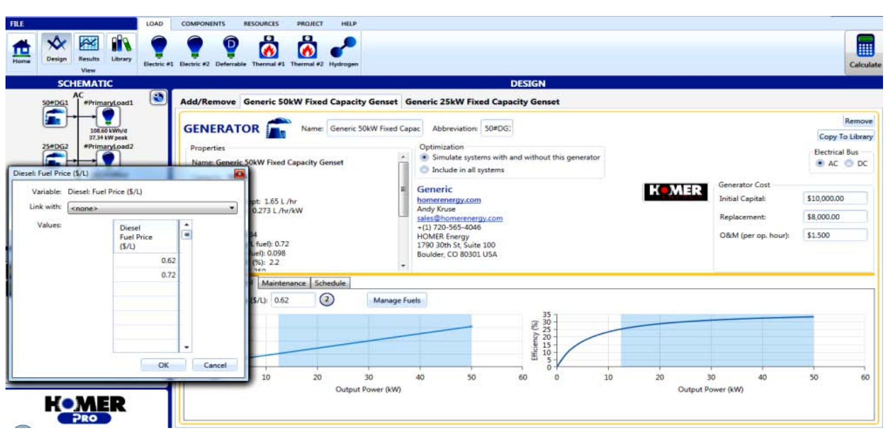
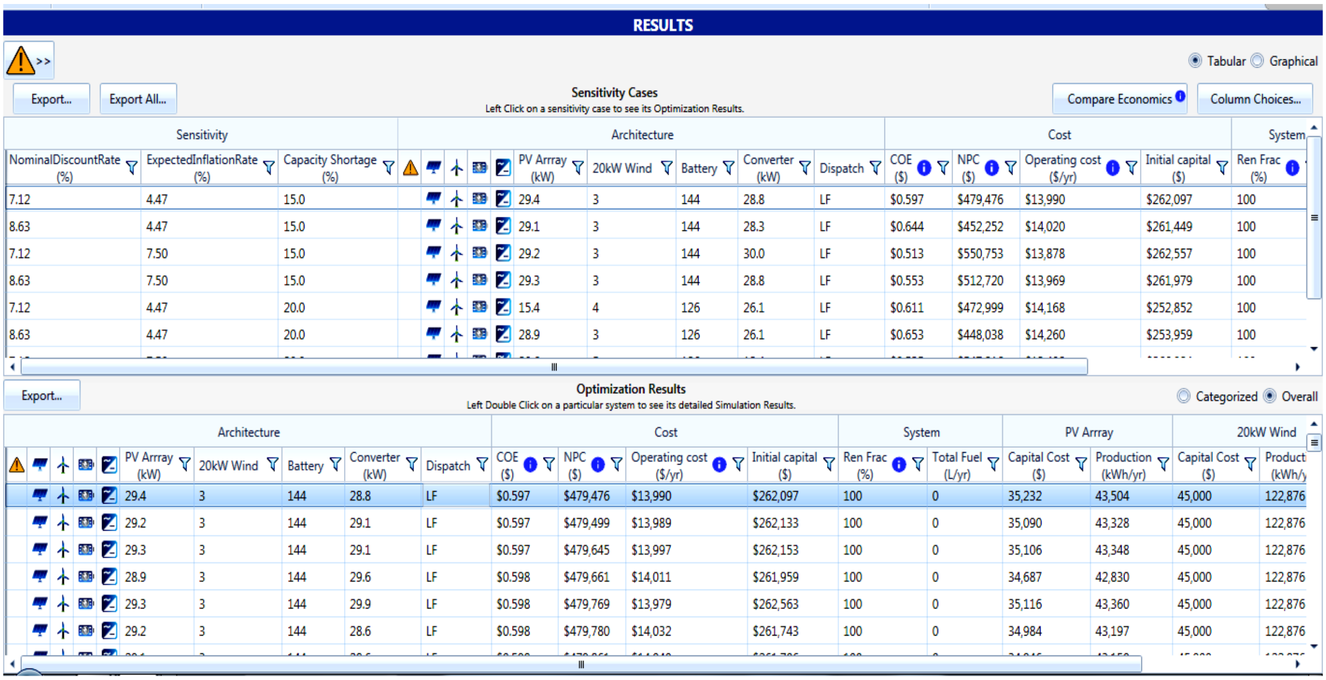


Fig.18: Inputs of Diesel Generator1 (50 kW of Diesel Mini-Grid, M4)

III. Results and Discussions

The thousands of Techno-Economic designs simulated for the four Models in HOMER Pro. Then, the optimum designs calculated with the Tabular results of two: the upper portion is the Sensitivity Cases and the lower portion is the Optimization Results as reflected in Figs. 19 to 22. The displayed results are listed for the models from the top to bottom of the optimistic to the least cost-effective options [24]. M1 to M3 connected with the different demands. Hence, the different capacities of the Architecture, the costs, system and other respective results predicted. The outcomes of M4 (the same demands as M3 with the different type of generation) reflected its consequent negative impacts.



RESULTS

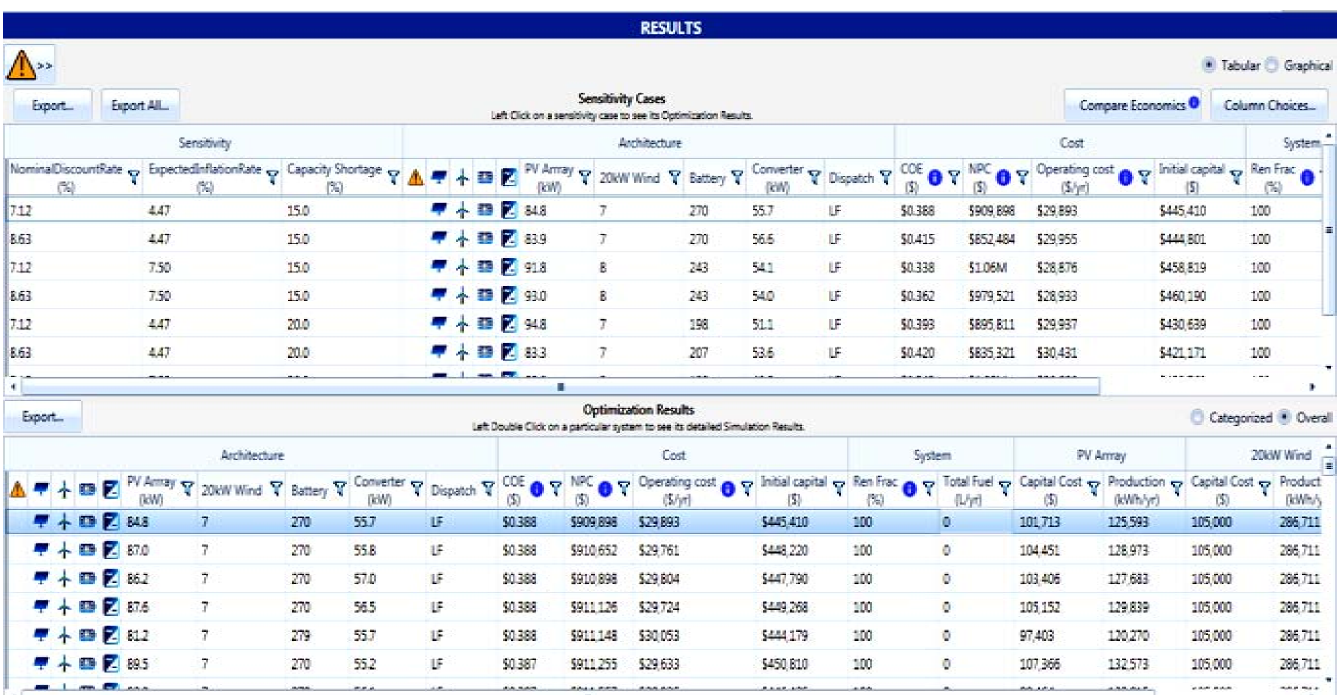
Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

Sensitivity			Architecture					Cost				System
NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
7.12	4.47	15.0	29.4	3	144	28.8	LF	$0.597	$479,476	$13,990	$262,097	100
8.63	4.47	15.0	29.1	3	144	28.3	LF	$0.644	$452,252	$14,020	$261,449	100
7.12	7.50	15.0	29.2	3	144	30.0	LF	$0.513	$550,753	$13,878	$262,557	100
8.63	7.50	15.0	29.3	3	144	28.8	LF	$0.553	$512,720	$13,969	$261,979	100
7.12	4.47	20.0	15.4	4	126	26.1	LF	$0.611	$472,999	$14,168	$252,852	100
8.63	4.47	20.0	28.9	3	126	26.1	LF	$0.653	$448,038	$14,260	$253,959	100

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System		PV Array		20kW Wind	
PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Capital Cost ($)	Product (kWh/y
29.4	3	144	28.8	LF	$0.597	$479,476	$13,990	$262,097	100	0	35,232	43,504	45,000	122,876
29.2	3	144	29.1	LF	$0.597	$479,499	$13,989	$262,133	100	0	35,090	43,328	45,000	122,876
29.3	3	144	29.1	LF	$0.597	$479,645	$13,997	$262,153	100	0	35,106	43,348	45,000	122,876
28.9	3	144	29.6	LF	$0.598	$479,661	$14,011	$261,959	100	0	34,687	42,830	45,000	122,876
29.3	3	144	29.9	LF	$0.598	$479,769	$13,979	$262,563	100	0	35,116	43,360	45,000	122,876
29.2	3	144	28.6	LF	$0.598	$479,780	$14,032	$261,743	100	0	34,984	43,197	45,000	122,876

Fig.19: Simulative Tabular Results of M1 in HOMER Pro



RESULTS

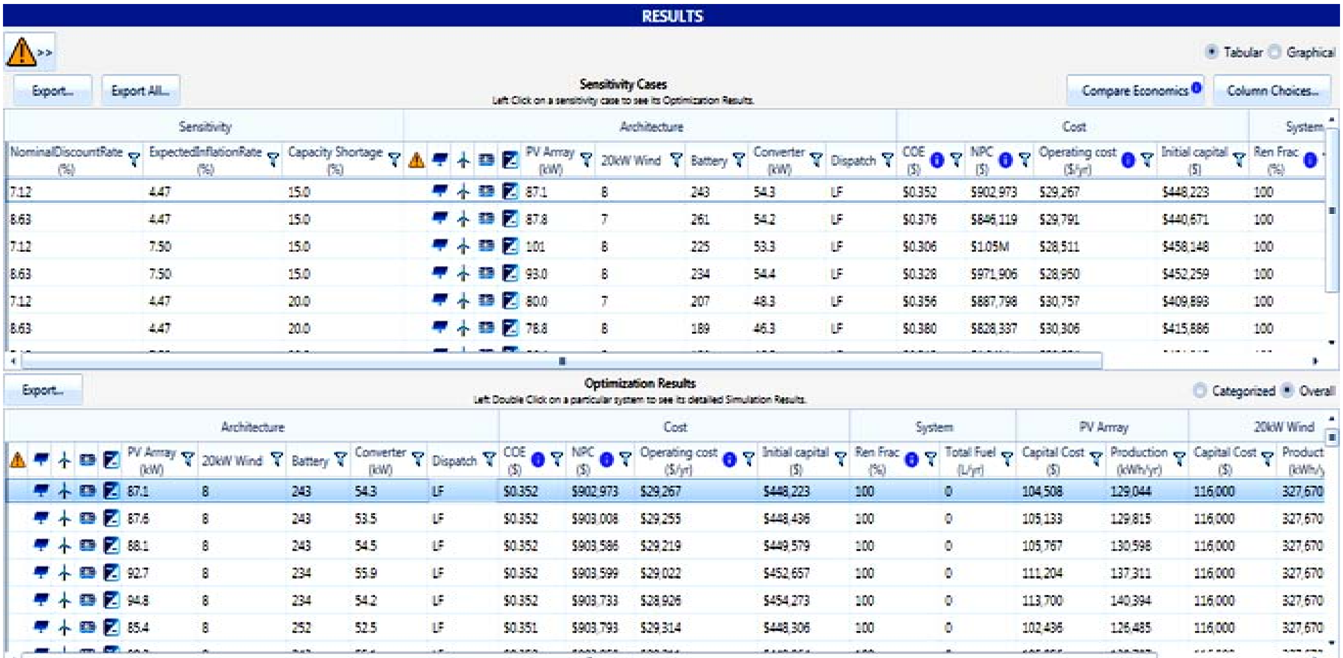
Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

Sensitivity			Architecture					Cost				System
NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
7.12	4.47	15.0	84.8	7	270	55.7	LF	$0.388	$909,898	$29,893	$445,410	100
8.63	4.47	15.0	83.9	7	270	56.6	LF	$0.415	$852,484	$29,955	$444,801	100
7.12	7.50	15.0	91.8	8	243	54.1	LF	$0.338	$1.06M	$28,876	$458,819	100
8.63	7.50	15.0	93.0	8	243	54.0	LF	$0.362	$979,521	$28,933	$460,190	100
7.12	4.47	20.0	94.8	7	198	51.1	LF	$0.393	$895,811	$29,937	$430,639	100
8.63	4.47	20.0	83.3	7	207	53.6	LF	$0.420	$835,321	$30,431	$421,171	100

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture					Cost				System		PV Array		20kW Wind	
PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Capital Cost ($)	Product (kWh/y
84.8	7	270	55.7	LF	$0.388	$909,898	$29,893	$445,410	100	0	101,713	125,593	105,000	286,711
87.0	7	270	55.8	LF	$0.388	$910,652	$29,761	$448,220	100	0	104,451	128,973	105,000	286,711
86.2	7	270	57.0	LF	$0.388	$910,898	$29,804	$447,790	100	0	103,406	127,683	105,000	286,711
87.6	7	270	56.5	LF	$0.388	$911,126	$29,724	$449,268	100	0	105,152	129,839	105,000	286,711
81.2	7	279	55.7	LF	$0.388	$911,148	$30,053	$444,179	100	0	97,403	120,270	105,000	286,711
89.5	7	270	55.2	LF	$0.387	$911,255	$29,633	$450,810	100	0	107,366	132,573	105,000	286,711

Fig. 20: Simulative Tabular Results of M2 in HOMER Pro



RESULTS

Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

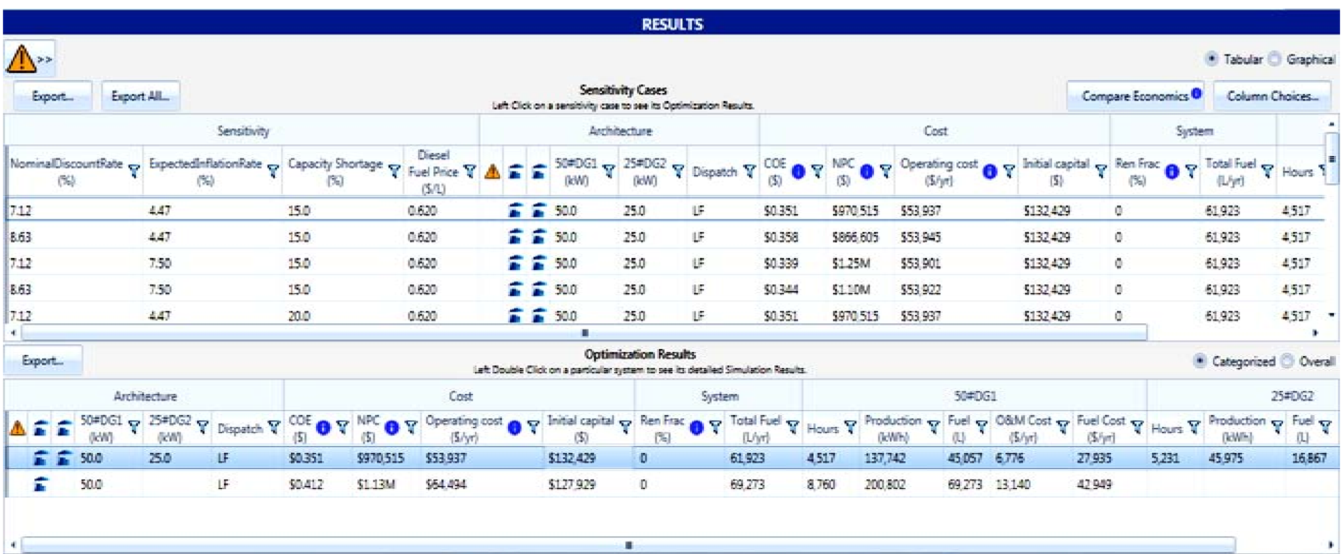
NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
7.12	4.47	15.0	87.1	8	243	54.3	LF	$0.352	$902,973	$29,267	$448,223	100
8.63	4.47	15.0	87.8	7	261	54.2	LF	$0.376	$846,119	$29,791	$440,671	100
7.12	7.50	15.0	101	8	225	53.3	LF	$0.306	$1.05M	$28,511	$458,148	100
8.63	7.50	15.0	93.0	8	234	54.4	LF	$0.328	$971,906	$28,950	$452,259	100
7.12	4.47	20.0	80.0	7	207	48.3	LF	$0.356	$887,798	$30,757	$409,893	100
8.63	4.47	20.0	76.8	8	189	46.3	LF	$0.380	$828,337	$30,306	$415,886	100

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

PV Array (kW)	20kW Wind	Battery	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	PV Array Capital Cost ($)	PV Array Production (kWh/yr)	20kW Wind Capital Cost ($)	20kW Wind Product (kWh/)
87.1	8	243	54.3	LF	$0.352	$902,973	$29,267	$448,223	100	0	104,508	129,044	116,000	327,670
87.6	8	243	53.5	LF	$0.352	$903,008	$29,255	$448,436	100	0	105,133	129,815	116,000	327,670
88.1	8	243	54.5	LF	$0.352	$903,586	$29,219	$449,579	100	0	105,767	130,598	116,000	327,670
92.7	8	234	55.9	LF	$0.352	$903,599	$29,022	$452,657	100	0	111,204	137,311	116,000	327,670
94.8	8	234	54.2	LF	$0.352	$903,733	$28,926	$454,273	100	0	113,700	140,394	116,000	327,670
85.4	8	252	52.5	LF	$0.351	$903,793	$29,314	$448,306	100	0	102,436	126,485	116,000	327,670

Fig. 21: Simulative Tabular Results of M3 in HOMER Pro



RESULTS

Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

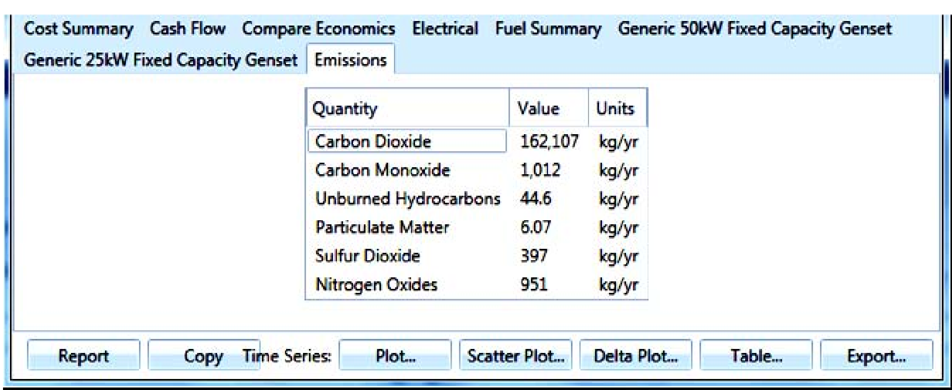
NominalDiscountRate (%)	ExpectedInflationRate (%)	Capacity Shortage (%)	Diesel Fuel Price ($/L)	50#DG1 (kW)	25#DG2 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours
7.12	4.47	15.0	0.620	50.0	25.0	LF	$0.351	$970,515	$53,937	$132,429	0	61,923	4,517
8.63	4.47	15.0	0.620	50.0	25.0	LF	$0.358	$866,605	$53,945	$132,429	0	61,923	4,517
7.12	7.50	15.0	0.620	50.0	25.0	LF	$0.339	$1.25M	$53,901	$132,429	0	61,923	4,517
8.63	7.50	15.0	0.620	50.0	25.0	LF	$0.344	$1.10M	$53,922	$132,429	0	61,923	4,517
7.12	4.47	20.0	0.620	50.0	25.0	LF	$0.351	$970,515	$53,937	$132,429	0	61,923	4,517

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

50#DG1 (kW)	25#DG2 (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	50#DG1 Hours	50#DG1 Production (kWh)	50#DG1 Fuel (L)	50#DG1 O&M Cost ($/yr)	50#DG1 Fuel Cost ($/yr)	25#DG2 Hours	25#DG2 Production (kWh)	25#DG2 Fuel (L)
50.0	25.0	LF	$0.351	$970,515	$53,937	$132,429	0	61,923	4,517	137,742	45,057	6,776	27,935	5,231	45,975	16,867
50.0		LF	$0.412	$1.13M	$64,494	$127,929	0	69,273	8,760	200,802	69,273	13,140	42,949			

Fig. 22: Simulative Tabular Results of M4 (Diesel Mini-Grid) in HOMER Pro



Cost Summary | Cash Flow | Compare Economics | Electrical | Fuel Summary | Generic 50kW Fixed Capacity Genset | Generic 25kW Fixed Capacity Genset | Emissions

Quantity	Value	Units
Carbon Dioxide	162,107	kg/yr
Carbon Monoxide	1,012	kg/yr
Unburned Hydrocarbons	44.6	kg/yr
Particulate Matter	6.07	kg/yr
Sulfur Dioxide	397	kg/yr
Nitrogen Oxides	951	kg/yr

Report | Copy | Time Series: | Plot... | Scatter Plot... | Delta Plot... | Table... | Export...

Fig. 23: Simulative GHG Emissions Results of M4 (Diesel Mini-Grid) in HOMER Pro

Table 4: Comparison of the Main Results of Four Models

Model	Design	Capacity	Annual Production/ Throughput (kWh/yr)	Cost of Energy ($)	Net Present Cost ($)	Operating Cost ($/ yr)	Initial Capital ($)	Diesel Fuel		
								(L/yr)	($/L)	($/yr)
M1	PV	29.4 kW	43504	0.597	479476	13990	262097	-	-	-
	Wind	60 kW	122876							
	Battery	144 kWh	19037							
	Converter	28.8 kW	-							
M2	PV	84.8 kW	125593	0.388	909898	29893	448220	-	-	-
	Wind	140 kW	286711							
	Battery	270 kWh	38361							
	Converter	55.7 kW	-							
M3	PV	87.1 kW	129044	0.352	902973	29267	448223	-	-	-
	Wind	160 kW	327670							
	Battery	243 kWh	34360							
	Converter	54.3 kW	-							
M4	DG1	50	137742	0.351	970515	53937	132429	45057	0.62	27935
									0.72	32441
	DG2	25	45975					16867	0.62	10457
									0.72	12144

The main results of four models mentioned in Table 4. M3 can supply all demands with the lowest cost of energy (COE) among three Models of PV-Wind-Battery Hybrid. Also, it observed that COE of M3 and M4 are not much differed. Fig. 23 mentioned the evident Emissions, the six pollutants from M4. There are no Diesel fuel consumptions, Diesel fuel costs, and no impacts (zero GHG Emission) by M3. Thus, M3 is selected as the proposed system of this research. Figs. 24 to 33 revealed the graphical results of M3.

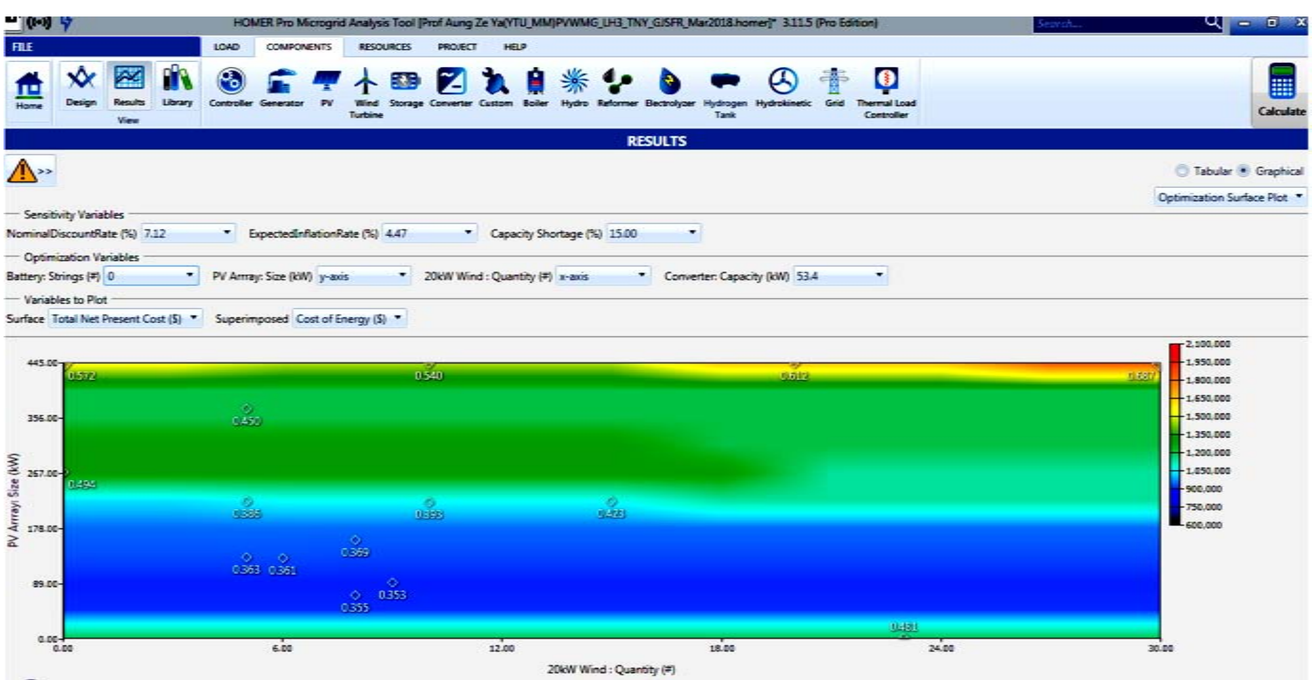


Fig. 24: Simulative Results: Optimization Surface Plot of PV Array vs. Wind with Variables: Total NPC and COE

In Fig.25, the less portion of yellow color around the middle of year (during rainy season) reflects the decrement of PV power output. In Fig. 26, the large portions of the red and yellow colors represent the large Wind power outputs near the middle and end of the year. Its blue color shows the less Wind power outputs.

It is clear that Wind power can compensate the period of less PV generation. PV can also support the large generation when Wind power decreases in the hot season. By implementing the PV or Wind only Mini-Grid at the focused village Lel Hpet, these advantages from PV-Wind Hybrid cannot be achieved.

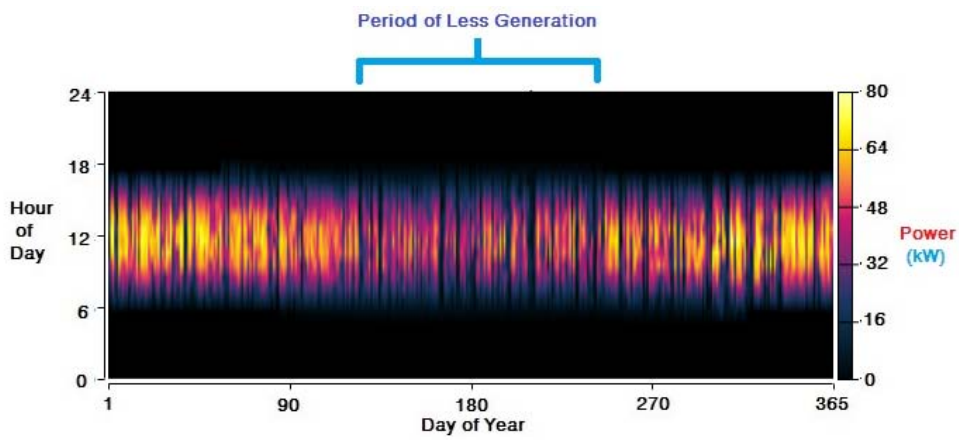


Fig. 25: Simulative Results: PV Power Output of Proposed Zero-Emission, PV-Wind-Battery Hybrid

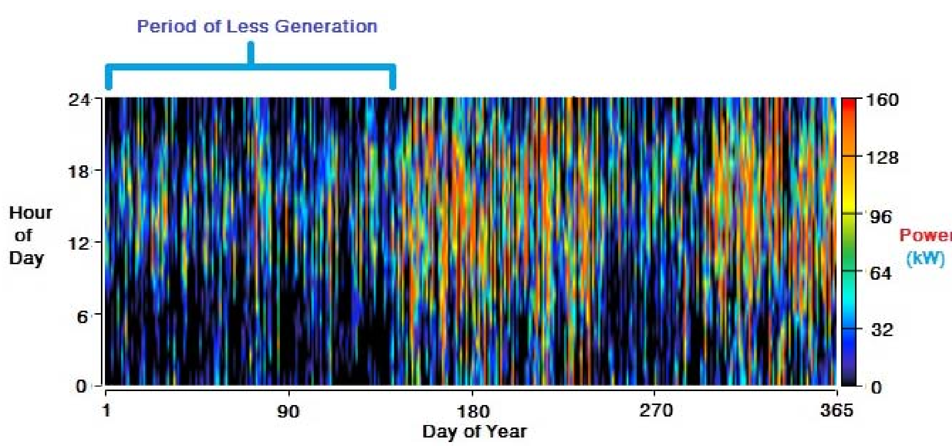


Fig. 26: Simulative Results: Wind Turbine Power Output of Proposed Zero-Emission, PV-Wind-Battery Hybrid

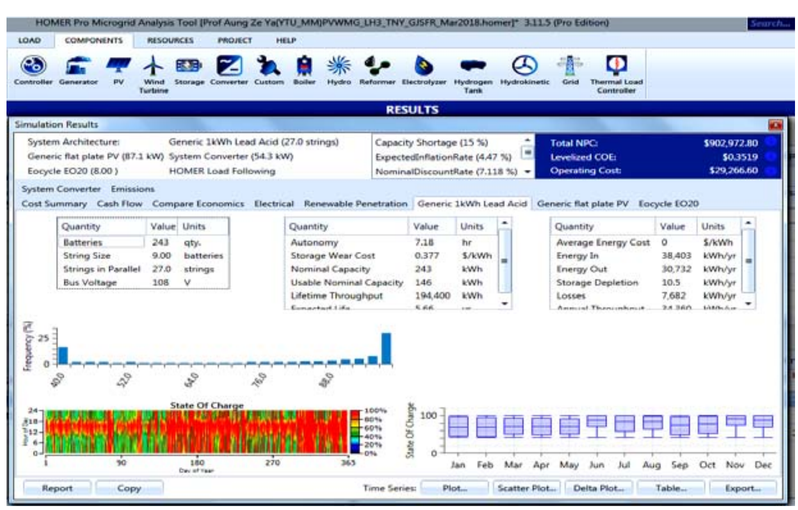


Fig. 27: Simulative Results: Storage Battery System of Proposed Zero-Emission, PV-Wind-Battery Hybrid

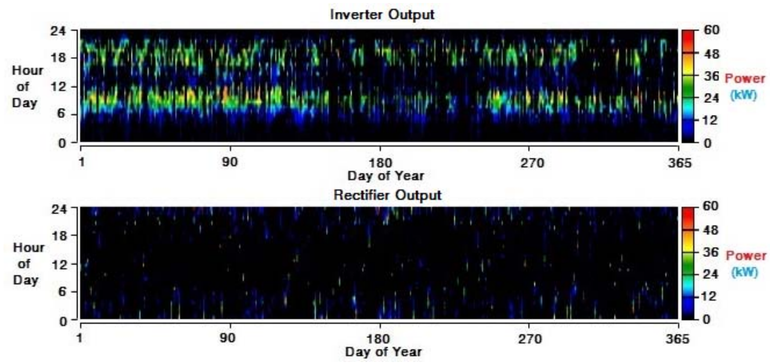


Fig. 28: HOMER Pro Simulative Results: Converter of Proposed Zero-Emission, PV-Wind-Battery Hybrid

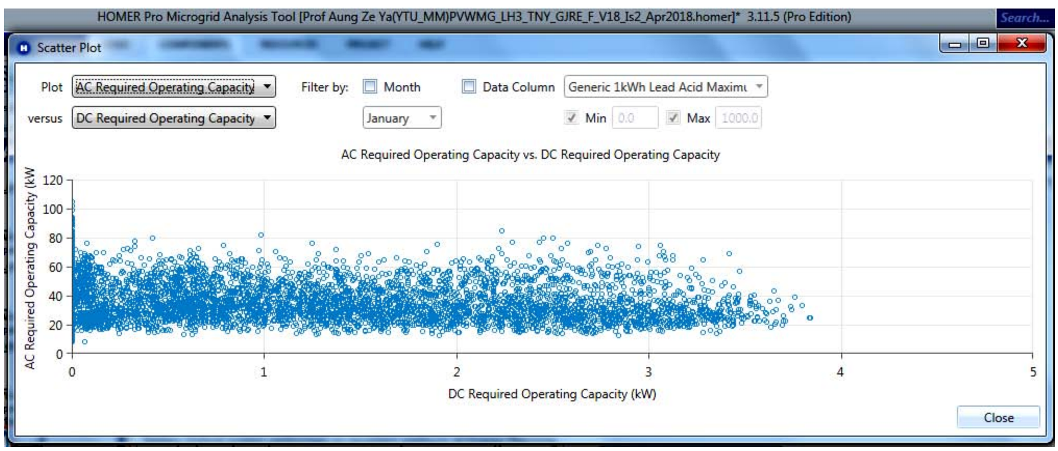


Fig. 29: Simulative Results: Scatter Plot of AC Required Operating Capacity vs. DC Required Operating Capacity

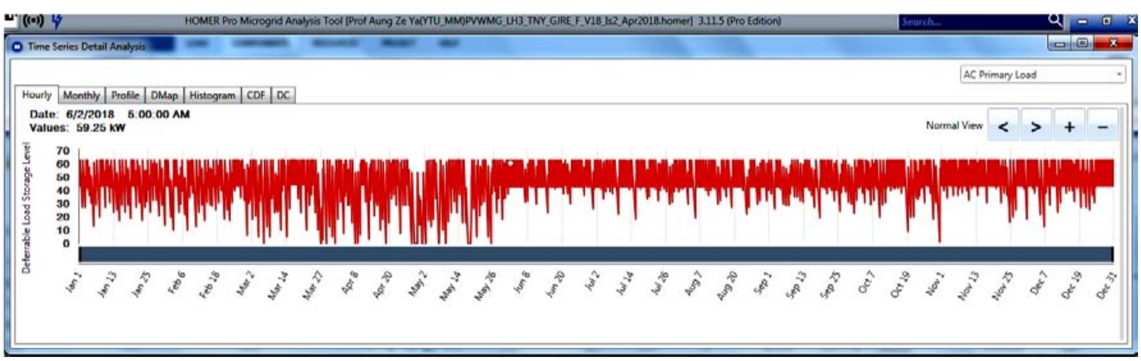


Fig. 30: HOMER Pro Simulative Results: Time Series Detail Analysis of the Deferrable Load Storage Level

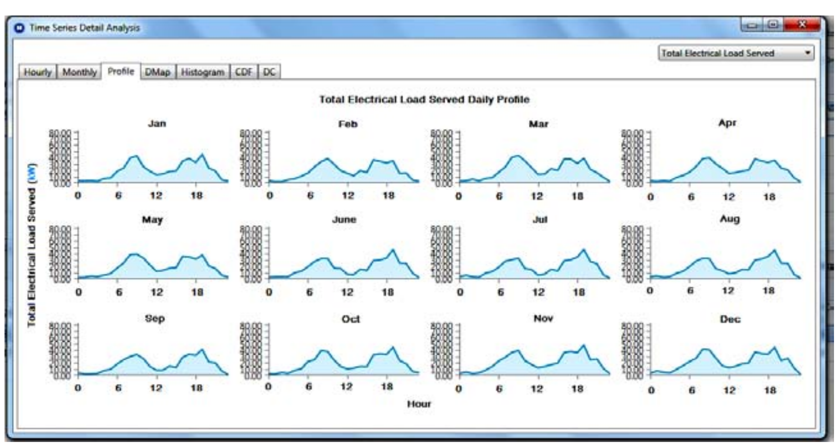


Fig. 31: HOMER Pro Simulative Results: Time Series Detail Analysis of the Total Electrical Load Served Daily Profile

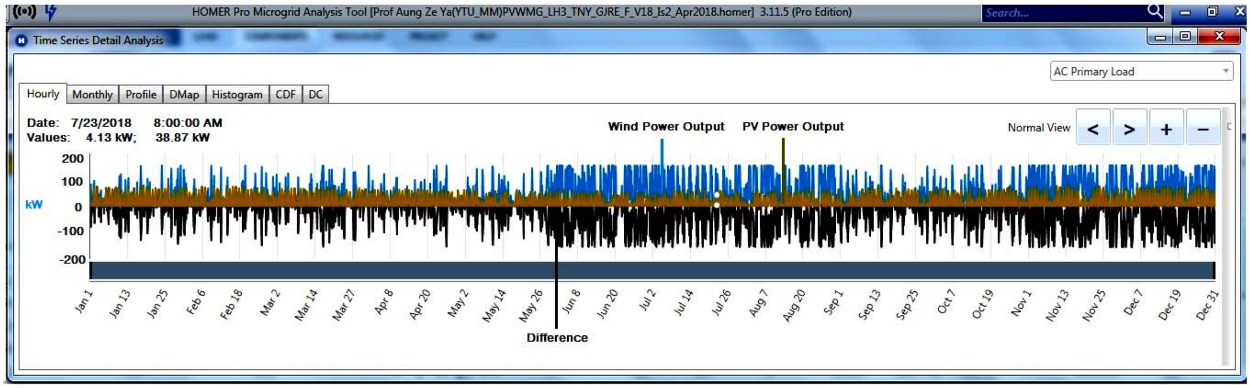


Fig. 32: Simulative Results: Time Series Detail Analysis of the Difference: Wind Power vs. PV Power Output

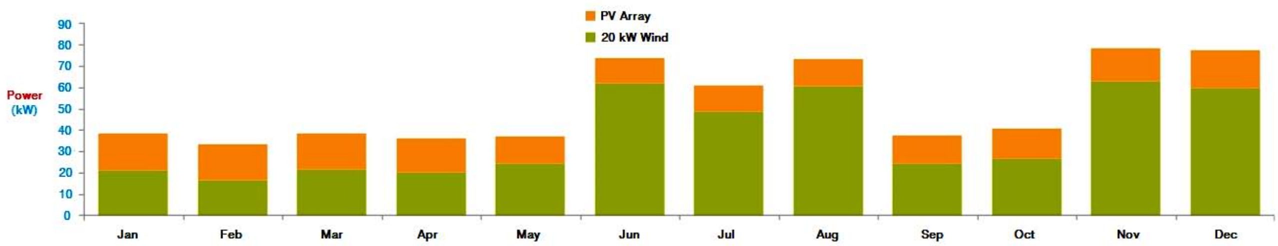


Fig. 33: Simulative Results: Monthly Average Generation of Proposed Zero-Emission, PV-Wind-Battery Hybrid

IV. Conclusions

The Off-Grid option is included in Myanmar's 2030 NEP (National Electrification Planning towards Universal Access). The Off-Grid Rural Electrification rate is about 36% by the end of 2017 [12]. It is in dire need to promote for the development of the whole country. This work contributes in that Mission as well as the priority of the conservation of Coastal Eco-System. Also, it is in line with the Goal 7 of the world's 2030 Agenda: 17 SDGs (Sustainable Development Goals) [25, 26].

Three HOMER Pro Models of PV-Wind-Battery Hybrid Mini-Grids with different demands compared and the lowest COE resulted from the Model with the largest capacities of main components. This recommends the capacity of Off-Grid Mini-Grid should be large from the economical point of view. The defined problems can be solved by the implementation of the proposed one. It can fulfill the villagers' dreams of the sufficient Electricity to the village Lel Hpet with 24-hour supply and improve their Socio-Economic Development.

The capacities of the proposed Model (M3) are: PV 87.1 kW (annual generation 129044 kWh/yr), Wind 160 kW (annual generation 327669 kWh/yr), Battery 243 kWh, and the converter 54.3 kW. In annual generation-mix, Wind shares 71.7% and PV shares 28.3%. Thus, it proved Wind power is more beneficial than PV power in Tanintharyi Coast, Southern Myanmar. 27 battery strings (9 batteries per string) are connected in parallel and the Bus voltage is 108 V. The battery capacities are: Energy Input 38403 kWh/yr, Energy Output 30732 kWh/yr, Annual Throughput 34360 kWh/yr, Lifetime Throughput 194400 kWh/yr, and Expected Life 5.66 years. The financial parameters of M3 are: Net Present Cost 902973 $, COE 0.352 $, Operating Cost 29267 $, and Initial Cost 448223 $. The obvious savings by M3 are: the Diesel fuel consumption 61924 L/yr, the Diesel fuel cost; 38392 S/yr (for fuel price 0.62 $/L) and 44585 $/yr (for fuel price 0.72 $/L). In addition, the evident reductions of GHG Emissions are: Carbon Dioxide 162107 kg/yr, Carbon Monoxide 1012 kg/yr, Unburned Hydrocarbons 44.6 kg/yr, Particular Matter 6.07 kg/yr, Sulfur Dioxide 397 kg/yr, and Nitrogen Oxides 951 kg/yr.

There is no doubt that this research work is instrumental for the strategic planning of standalone PV-Wind-Battery Hybrid Mini-Grid by applying Global Standard tool, HOMER Pro. This article obviously highlighted Sustainability benefits can be gained from Zero-Emission, 100 % Renewable Energy System at Off-Grid village that has abundant PV and Wind potentials.

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The Effect of Design Parameters on Induced Electromotive Force and Losses of PM Machines

By Chukwuemeka Chijioke Awah, Ogbonnaya Inya Okoro & Udochukwu Bola Akuru

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Abstract- The impact of machine geometry on the performance of double-stator synchronous permanent magnet (PM) machine having different rotor pole numbers is investigated in this paper. The considered design parameters include: the split-ratio, rotor radial thickness, stator back-iron thickness, and rotor inner and outer radial lengths. It is observed that, there are optimum values for each of the design elements due to the changing condition of the electromagnetic reaction. Comprehensive analysis of the effects of the above mentioned design parameters on the fundamental back-electromotive force (EMF) and losses are given. The analysis shows that the 7-rotor pole machine has the best efficiency as well as the largest fundamental EMF value. It is also observed that, the least PM eddy current loss in addition to least overall core loss of the machine is seen in the 5-rotor pole machine.

Keywords: design parameters, efficiency, fundamental back-EMF, losses and PM machines.

GJRE-F Classification: FOR Code: 290903

THEEFFECTOFDESIGNPARAMETERSONINDUCEDELECTROMOTIVEFORCEANDLOSSESOFPMMACHINES

Strictly as per the compliance and regulations of:

The Effect of Design Parameters on Induced Electromotive Force and Losses of PM Machines

Chukwuemeka Chijioke Awah [α], Ogbonnaya Inya Okoro [σ] & Udochukwu Bola Akuru [ρ]

Abstract- The impact of machine geometry on the performance of double-stator synchronous permanent magnet (PM) machine having different rotor pole numbers is investigated in this paper. The considered design parameters include: the split-ratio, rotor radial thickness, stator back-iron thickness, and rotor inner and outer radial lengths. It is observed that, there are optimum values for each of the design elements due to the changing condition of the electromagnetic reaction. Comprehensive analysis of the effects of the above mentioned design parameters on the fundamental back-electromotive force (EMF) and losses are given. The analysis shows that the 7-rotor pole machine has the best efficiency as well as the largest fundamental EMF value. It is also observed that, the least PM eddy current loss in addition to least overall core loss of the machine is seen in the 5-rotor pole machine.

Keywords: design parameters, efficiency, fundamental back-EMF, losses and PM machines.

I. Introduction

DEVELOPMENT of high energy rare-earth materials as well as recent trends in power electronics and computer-aided tools have given rise to tremendous research on permanent magnet machines. Thus, the double-stator PM-, double-rotor PM- and flux switching PM machines are readily available and are demonstrated in the following literature [1], [2] and [3]. Similarly, flux modulated PM machines based on magnetic gearing principles are gaining wide attraction owing to their advantages of high output torque and efficiency as shown in [4] and [5].

The impact of design parameters have been researched extensively due to its great influence on the overall performance of electrical machines. It is proven in [6] that, design parameters such aspect ratio also known as split ratio, pole number, weight etc. are important factors to be considered during electrical machine design due to their influences on efficiency, torque density and cost. Furthermore, detailed account of the influence of key design parameters on power factor of an integrated PM machine, as well as means of enhancing the power factor of the given electric machine by appropriate selection of the PM pole-pairs is given in [7].

Moreover, the effect of different design elements of surface-mounted PM vernier machine on the overall performance of the machine is presented in [8]. The analysis shows that the design parameters have significant impact on the performance of the machine in terms of torque and power factor potentials. Thus, optimal value of the parameters must be used in order to achieve the best result.

A novel topology of dual excited PM machine with improved torque capacity is proposed in [9]. The given machine is suitable for direct drive applications since it could produce large torque at low operating speed. Further, novel two-phase double stator PM machine having concentrated windings and spoke-mounted PMs is proposed in [10]. The proposed machine in [10], is capable of producing larger torque density compared to that of traditional PM machine; albeit, with higher induced EMF harmonics.

Similarly, comparative study of flux switching PM (FSPM) machine and Toyota Prius IPM motor is given in [11]. The investigation shows that, although, the FSPM machine have lots of advantages such as better suitability for brushless AC control and low torque ripple over the IPM, it also have some drawbacks such as high PM usage and manufacturing cost.

Due to the fluctuating price and limited availability of rare-earth magnets, several machines which utilizes less or no PMs such switched reluctance machine (SRM), induction machine (IM) and PM-assisted synchronous machines equipped with ferrite magnets are reviewed and quantitatively compared in [12], without significant trade-off of its efficiency and output torque capability. Further works on cost-effective PM machines with little or no rare-earth magnet materials such as dysprosium are detailed in [13] and [14]; however, with increased risk of demagnetization.

In this work, the impact of leading design geometry such as the split ratio, rotor radial thickness, back-iron thickness etc. on the fundamental back-EMF as well as the losses of double-stator flux switching PM (DS-SFPM) machine are considered.

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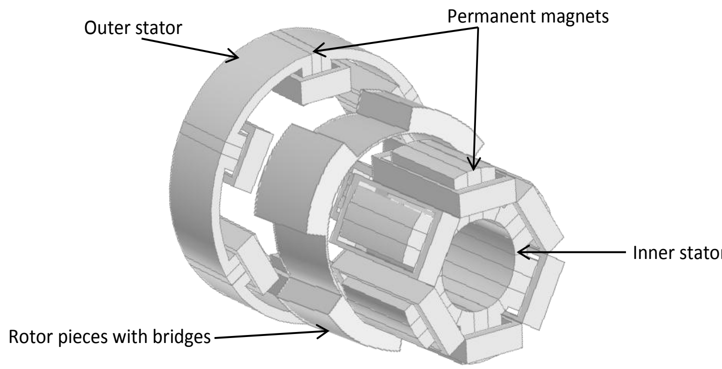


Fig. 1: Structural view of the developed DS-SFPM machine.

A two-dimensional finite element analysis (2D-FEA) is employed in prediction of the entire results in this study. Moreover, comparison of the obtained results having different rotor pole numbers is also given. It should be noted that, the outer stator radius of the analyzed machine is 45mm with stack and air-gap lengths of 25mm and 0.5mm, respectively. Fig. 1 shows the structural view of the developed PM machine.

II. Electromagnetic Performance

An optimal split-ratio value of about 0.55 is obtained in most of the analyzed machines except in that of 4-rotor pole machine whose optimum split-ratio value is about 0.67. This is evidenced in Fig. 2. It is worth noting that, the largest fundamental back-EMF value occurs in the 7-rotor pole machine, in all the investigated conditions, owing to its higher flux-linkage value. The induced electromotive force of the analyzed double-stator machine is given in equation (1), as the rate of flux-linkage with time. Thus,

$$E = -\frac{d\psi}{dt} = -N\omega\frac{d\varphi}{d\theta} \tag{1}$$

where ψ is flux-linkage, $\varphi=$ flux per pole, N is number of turns per phase, θ is the rotor position, and ω is the rotational speed.

Further, the split-ratio of the analyzed machines is given as the ratio of the outer air-gap to the outer radius of the machine as given in equation (2).

$$S_R = \frac{R_{oag}}{R_{out}} \tag{2}$$

where *SR* is the split or aspect ratio of the machine, *Roag=* the radius of the outer air-gap, radius of the machine's outer size.

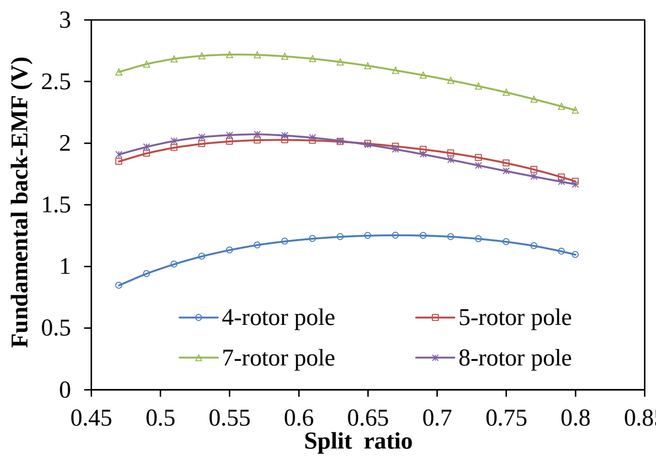


Fig. 2: Variation of back-EMF with split ratio, no load.

As the radial thickness increases the time rate of change of flux per pole also increases, resulting to high back-EMF value. This increase will continue until the available slot area for the windings begins to decrease due to the increased size of the rotor width. This will eventually lead to reduced induced EMF as seen in Fig. 3.

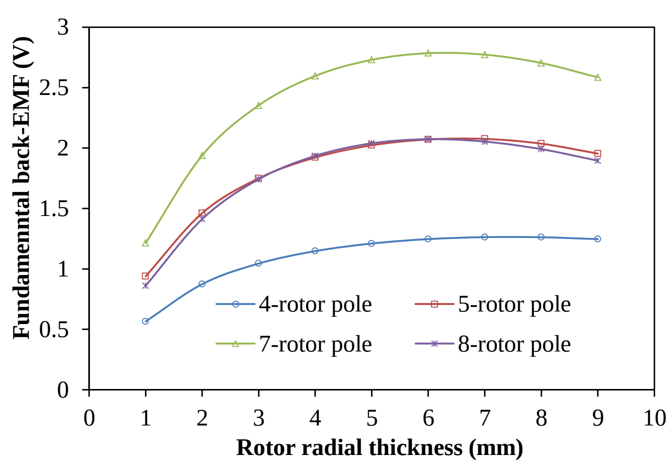


Fig. 3: Variation of back-EMF with rotor radial thickness, no load.

The variation of back-EMF with both the rotor outer and inner arcs/pitch ratio shown in Figs. 4 and 5, increases as the arc lengths increases, until it gets to its optimum peak value at the range of ~0.4-0.5 (for the different rotor poles), before decreasing due to the changing rate of flux linkage at each instance. Thus, there is an optimum value of the arcs to yield the maximum fundamental flux-linkage and EMF values.

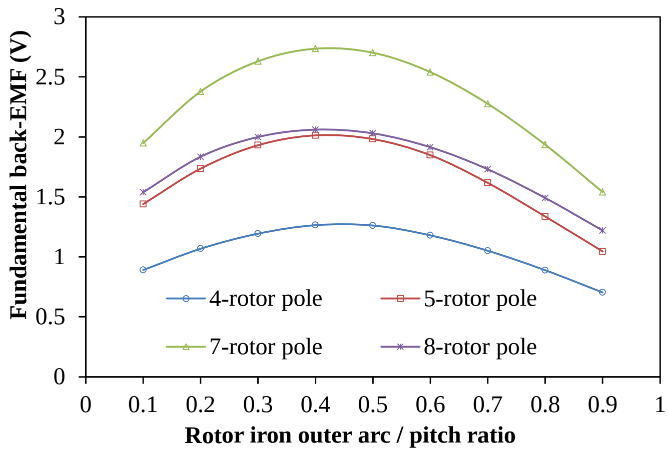


Fig. 4: Variation of back-EMF with rotor outer arc/pitch ratio.

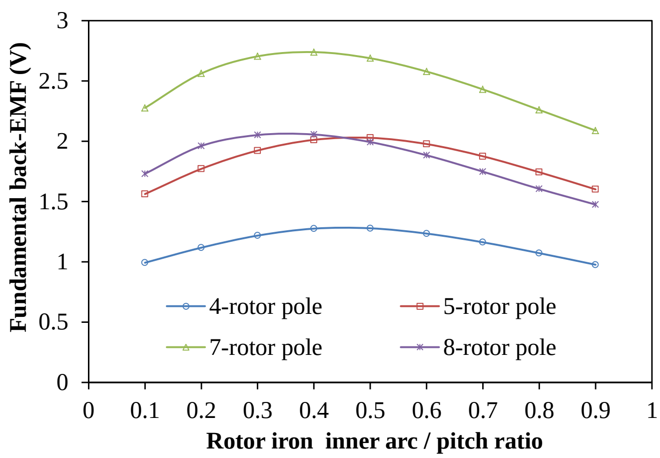


Fig. 5: Variation of back-EMF with rotor inner arc/pitch ratio.

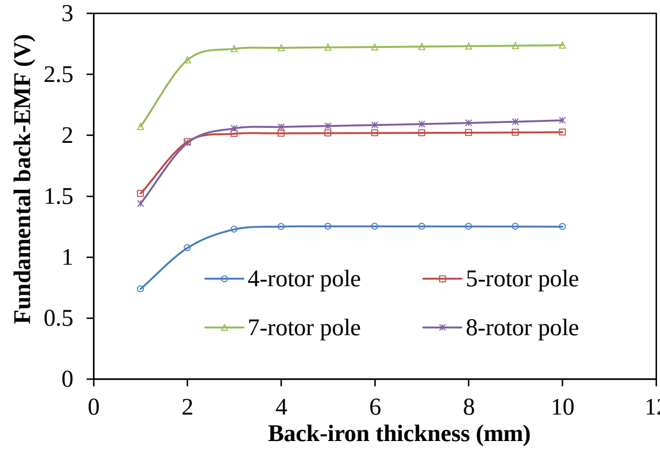


Fig. 6: Variation of back-EMF with back-iron thickness, no load.

There is initial sharp increase in the fundamental value of the EMF as the size of the back-iron increases owing to high distribution of the PM flux on the back-iron until about 2mm before deceasing as the flux leaks away due to the huge thickness of the stator yoke. The variation of induced EMF with stator back-iron is depicted in Fig. 6.

III. Effect of Design Geometry on Losses

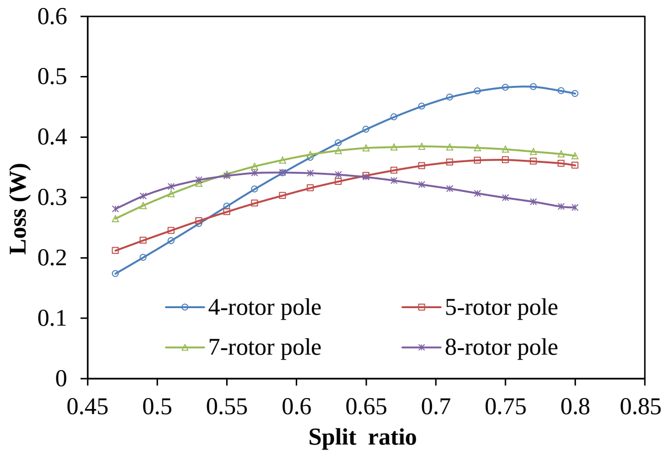
Since the output of electrical machines are dependent on its losses, therefore, accurate prediction of losses in electrical machines could help to give insight about its thermal/heat dissipation design limits. Hence, we have devoted this section to the investigation of permanent magnet eddy current loss and core loss analysis under no-load condition at low speed of 400rpm. The influence of the design parameters on the loss characteristics of the developed machines at no-load are displayed in Fig. 7(a)-(e). Depending on the objective(s), the machines could be designed to have minimum loss by employing the optimum values of the main design parameters.

It is worth noting from Fig. 7, that the 4-rotor pole machine exhibits the largest loss whilst the least loss occurs in the 5- rotor pole machine. The loss characteristics of the 7-and 8- rotor pole machines are almost identical in each variation with the leading design parameters.

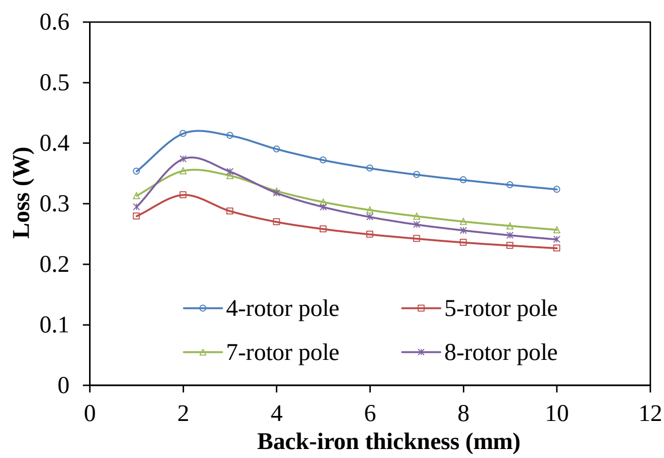
The predicted losses are calculated using the traditional Steinmetz equation given in (3).

$$P_{loss} = K_h B_m^2 f + K_e (B_m f)^{1.5} + K_c (B_m f)^2 \qquad (3)$$

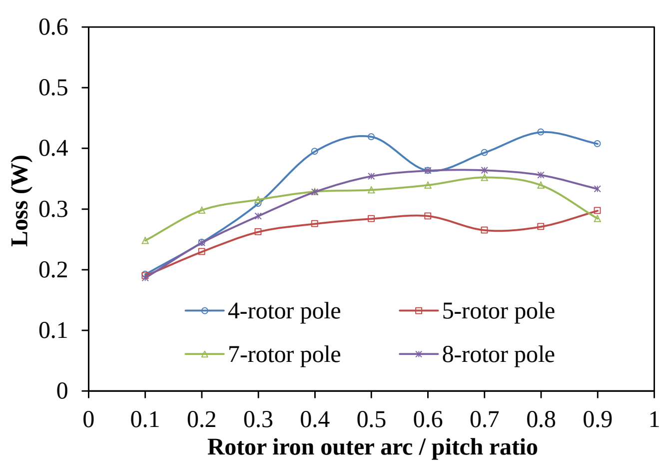
where *Bm* is the peak value of the flux density, *f* is the frequency; *Kh*, *Ke*, and *Kc* are the loss coefficients for hysteresis, excess and eddy current losses, respectively.



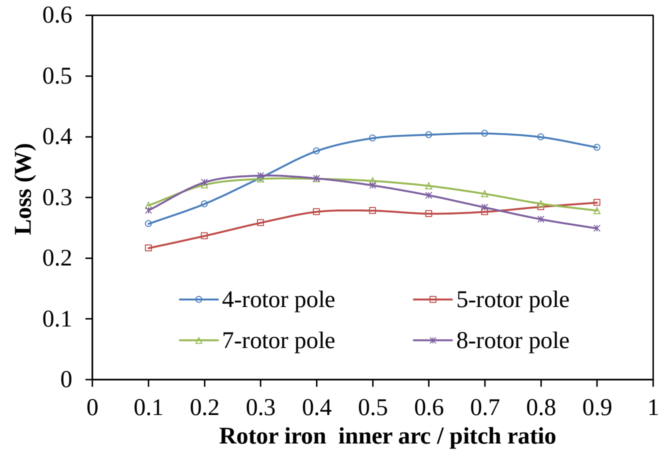
(a) Loss versus split ratio



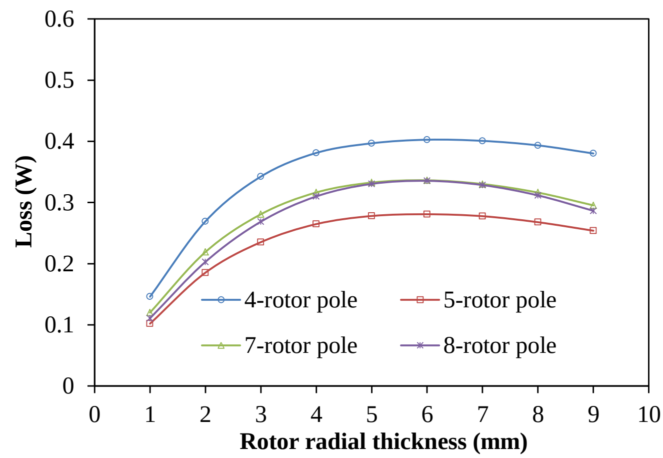
(b) Loss versus back-iron thickness



(c) Loss versus rotor iron outer arc / pitch ratio



(d) Loss versus rotor iron inner arc / pitch ratio



(e) Loss versus rotor radial thickness (mm)

Fig. 7: Variation of total core losses in DS-SFPM machines with design parameters, no load, 400rpm.

In each case, smaller split ratio will result to increased PM length and larger space for the windings, thus giving rise to an increased air-gap flux density. The reverse condition and corresponding opposite effect is also obtainable, giving room for optimum yield.

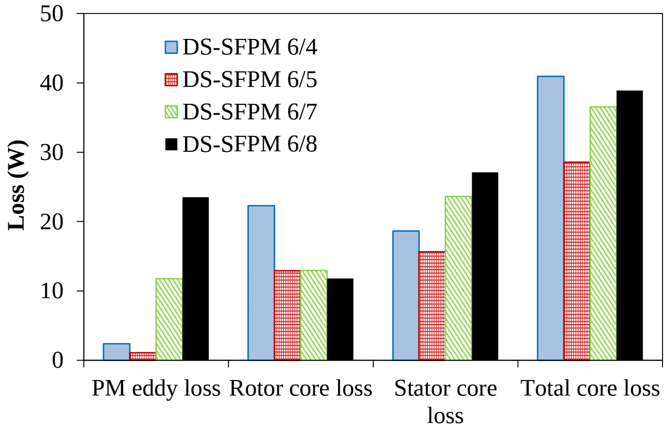


Fig. 8: Comparison of losses in DS-SFPM machines, I=15A, 4000rpm.

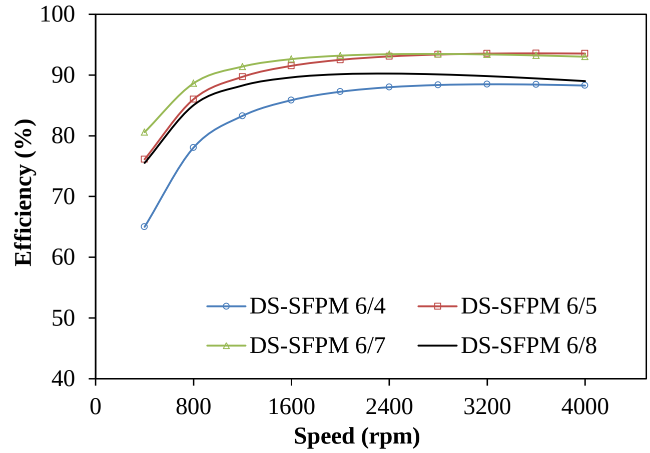


Fig. 9: Comparison of efficiency in DS-SFPM machines, copper loss=30W.

Note that, there is a sharp decrease in the loss variation with the back-iron thickness after about 2mm of the yoke size due to reduced space for the conductors as the back-iron increases. Note also, that a similar trend is observed in the variation of total core loss with the rotor radial thickness in all the investigated different rotor poles; although, with different amplitudes.

Furthermore, the comparison of both PM eddy current losses, and the core losses of the DS-SFPM machines are displayed in Fig. 8. The predicted results reveal that the 8-rotor pole machine has the highest value of PM eddy current loss due to its large amount of harmonics as well as relatively high electrical frequency, in addition to its PM usage, since the machines were optimized independently. Moreover, the 4-rotor machine exhibits the largest amount of total core loss amongst its counterparts. This is possibly due to its enormous harmonics, inherent in even rotor pole machines.

Fig. 9. shows the comparison of efficiency in the analysed machines, at different operating speed. It is obvious that, the odd rotor pole machines could produce better efficiencies, in particular, the 7-rotor pole machine compared to their even rotor pole counterparts. The worst case scenario being the 4- rotor pole machine.

IV. Conclusion

The influence of design parameters on the fundamental back-EMF and losses of double-stator PM machine is presented. It is observed that, there are optimum values for each of the design parameters owing to the varying electromagnetic reaction of the conducting coils. The analyses reveal that the 7-rotor pole machine exhibits the largest fundamental back-EMF as well as the best efficiency profile amongst the analyzed machines. Further, it is found that the least amount of losses occurred in the 5-rotor pole machine while the worst machine in terms of overall performance is the 4-rotor pole machine mainly due to its enormous harmonic characteristics.

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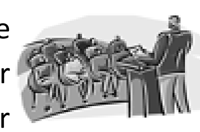

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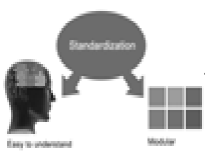

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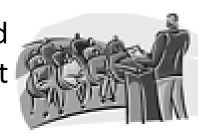

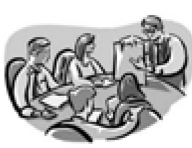

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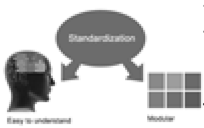

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c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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