IEET

International Electrical Engineering Transactions

Vol. 1 No. 1
July – December 2015
ISSN 2465-4256

An online publication of the EEAAT
Electrical Engineering Academic Association (Thailand)
www.journal.eeaat.or.th

IEET – International Electrical Engineering Transactions

This journal is an online publication of the EEAAT, Electrical Engineering Academic Association (Thailand). IEET is published twice a year, ie., the first issue is for January – June and the second issue is for July – December.

IEET (International Electrical Engineering Transactions) is published twice a year. Original contributions covering work in all aspects of electrical science, technology, engineering, and applications will be peer-reviewed by experts before publication. Topics of interest include the following: electrical power, electronics, telecommunication, control and system, sensor and measurement, optical technology, computer, information and communication technology (ICT), signal processing, social network tools and applications (apps), engineering education and other related fields.

For online submission of all manuscripts, correspondences, and letters, please visit
www.journal.eeaat.or.th

IEET Editorial Office

EEAAT - Electrical Engineering Academic Association (Thailand)
Room 409, F-Building,140 Cheum-Sampan Rd.
Nong Chok, Bangkok, Thailand 10530
Tel: +662-988-3655 ext 2216 Fax: +662-988-4026

IEET - International Electrical Engineering Transactions
Volume 1
Number 1
July – December 2015

PAPERS

Speed and Position Estimation of Surface Permanent-Magnet Synchronous Motors with Global Stability based on a New Reduced-Order Model

Prachuab Iamsamang and **Somboon Sangwongwanich**

Manuscript received November 15, 2015
Revised December 11, 2015

ABSTRACT

This paper proposes a new reduced-order model for a surface permanent-magnet synchronous motor (SPMSM). A position estimator with global stability is then designed based on the proposed model. Design criteria for stability, dynamic and tracking performances are clearly given. The importance of global stability is emphasized by comparison with the design with only local stability. Theoretical results are verified by simulation and experiment.

Keywords: *position estimator, SPMSM*

1. INTRODUCTION

Many researches on model-based position estimation of SPMSMs have been done till now [1] - [14]. Most estimators calculate the back EMF directly or use some kinds of observers to estimate the position. Conventional estimators based on the back EMF [1] need a filter to attenuate noises. This ruins the estimation accuracy and stability. Also, a phase-locked loop is often used therein to track the rotor position, but its convergence relies on small-signal approximation.

For the observer-based estimation, a full-order model [2][3] is a good candidate as for its linearity, but both position θ and speed ω appear as two parameters in the model, making the analysis complicated. Also, the magnet flux λ estimation is redundant and may become unreliable in a low speed range. On the contrary, a reduced-order model wherein the rotor flux is treated as a known quantity is discussed in e.g. [4] and [5]. However, the stability analysis is neither simple [4] nor rigorous [5].

To our knowledge, no estimation methods presented so far can guarantee global stability without approximation or some assumptions [1]-[5]. Linearization around an operating point makes the stability so-derived only a local one. Global stability is however an important issue from both theoretical and practical point of views.

In this paper, a new and simple reduced-order model of SPMSMs is introduced, based on which a position estimator is constructed. The main features of the proposed model and estimator are:

1) Position θ is the only unknown parameter in the model.
2) Global stability is guaranteed without approximation.
3) Design for tracking and stability is simple and clear.

This paper is organized as follows. First, the new reduced-order model is introduced in comparison with the full-order one. Then the position estimator based on the new reduced-order model will be explained, and its stability property will be analyzed. Design for tracking and dynamic performance will also be discussed, and effects of parameter variation on the estimation performances will be investigated. Finally, simulation and experiment will be given to confirm the validity of all theoretical results.

2 A NEW REDUCED-ORDER MODEL FOR SPMSM AND A REDUCED-ORDER OBSERVER

For the sake of comparison, the conventional full-order model of SPMSM is shown in (1). In there, all the voltage, current, and flux space vectors are referred to the same stator reference frame. As can be seen from (1), the model is linear which allows an application of linear estimation method, but at the expense of redundant estimation of the rotor flux. The model is of 4$^{\text{th}}$-order, which is higher than necessary considering that the magnitude of the flux vector λ is a known quantity. Also, the rotor position θ and speed ω are treated as two independent parameters, and are thus estimated independently in the estimator. As a result, in the estimator based on this full-order model [1][5] the estimated rotor position is not truly related to the estimated rotor speed by an integrator like in the real physical world.

<u>Conventional full-order model</u> :

$$\left.\begin{aligned} &\vec{v} = R\vec{i} + L\frac{d\vec{i}}{dt} + \boldsymbol{J}\omega\vec{\lambda} \\ &\frac{d\vec{\lambda}}{dt} = \boldsymbol{J}\omega\vec{\lambda}; \quad \vec{\lambda} = \begin{bmatrix} \lambda\cos\theta \\ \lambda\sin\theta \end{bmatrix} \end{aligned}\right\} \qquad (1)$$

Prachuab Iamsamang and Somboon Sangwongwanich are with the Dept. of Electrical Eng., Faculty of Engineering, Chulalongkorn University, Thailand (e-mail:somboona@chula.ac.th)

where $J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$, $^{-}$ denotes the space vector quantity.

$\vec{v}, \vec{i}$: stator voltage and current space vectors referred to stator reference frame.

$\vec{\lambda}$: rotor flux space vector referred to stator reference frame.

$\theta, \omega = d\theta / dt$: rotor angle and speed in electrical degrees.

R, L : stator resistance and inductance.

In contrast to the full-order model, a new reduced-order model of 2nd-order is introduced in the following. The key idea in the proposed reduced-order model is to express the voltage/current/flux variables in their own true coordinates ($\vec{v}, \vec{i}, \vec{\lambda}_r$) rather than as ($\vec{v}, \vec{i}, \vec{\lambda}$) which refer all the variables to the same stator frame.

New reduced-order model :

$$\vec{v} = R\vec{i} + L\frac{d\vec{i}}{dt} + \frac{d}{dt}(e^{J\theta}\vec{\lambda}_r); \quad \vec{\lambda}_r = \begin{bmatrix} \lambda \\ 0 \end{bmatrix} \tag{2}$$

where $\vec{\lambda}_r$ is the rotor flux space vector referred to its own rotor reference frame.

The advantage of using this reduced-order model is that all the variables $\vec{v}, \vec{i}, \vec{\lambda}_r$ become now measurable or known, and need no estimation. Compared to (1), the only unknown parameter in the model (2) is the rotor position θ. Therefore, the reduced-order model is very simple and reflects clearly the fundamental voltage equation of the stator winding and its coupling with the permanent-magnet flux. The only disadvantage of the model (2) is that the rotor position appears in the nonlinear exponential function. However, this causes no problem in construction of the estimator if the relevant stability can be proved. So, the difficulty lies only in the analysis not the synthesis part of the estimation.

Based on the reduced-order model (2), an observer can be constructed as shown in (3), and the estimated current error $\hat{\vec{i}} - \vec{i}$ can be used to estimate the rotor position and speed as explained in the sequel.

Reduced-order observer:

$$\vec{v} = R\hat{\vec{i}} + L\frac{d\hat{\vec{i}}}{dt} + \frac{d}{dt}(e^{J\hat{\theta}}\vec{\lambda}_r) + \mathbf{K}(\hat{\vec{i}} - \vec{i}) \tag{3}$$

Here $\hat{}$ denotes the estimated value, $\mathbf{K}$ is the error-feedback gain matrix of the observer.

3 GLOBAL STABILITY OF THE ESTIMATOR

In this section, the stability characteristic of the estimator under two kinds of feedback gain $\mathbf{K}$ will be analyzed. It will be shown that with an appropriate feedback gain the global stability will be attained; otherwise the stability will be guaranteed only locally. The importance of the global stability will also be illustrated by simulation.

a) Local stability with $\mathbf{K} = kI$

In this case, the feedback gain is the simplest one $\mathbf{K} = kI$, where I is the identity matrix. The effect of using this kind of feedback gain is equivalent to changing the resistance of the motor from R to $R+k$. The error equation for the estimated current can be derived as shown in (4).

$$\vec{e}_i = \hat{\vec{i}} - \vec{i} = \frac{1}{L}\frac{s}{s+a}\left(e^{J\theta} - e^{J\hat{\theta}}\right)\begin{bmatrix} \lambda \\ 0 \end{bmatrix}; \quad a = \frac{R+k}{L} \tag{4}$$

where $\vec{e}_i$ is the estimated current error. Using the estimated current error the position and speed estimators are constructed as shown in (5), wherein k_P, k_I are the adaptation PI gains.

Position/Speed estimator I:

$$\left.\begin{aligned} \hat{\omega} &= \left(k_P + k_I\int dt\right)[(-\mathbf{J}e^{J\hat{\theta}}\vec{\lambda}_r)^T(\hat{\vec{i}} - \vec{i})] \\ \hat{\theta} &= \int \hat{\omega}\,dt \qquad\qquad (k_I / k_P > 0) \end{aligned}\right\} \tag{5}$$

It is clear that the estimator is very simple, and the rotor position and speed are now related exactly by an integrator. The design parameters of this estimator are k, k_P, k_I which should be selected to guarantee stability and tracking of the changing rotor position and speed.

Assuming that the estimation error $\Delta\theta$ is small, the linearized error equation is obtained as (6).

$$\vec{e}_i \cong \boldsymbol{G}(s)\Delta\theta \boldsymbol{J} e^{J\hat{\theta}}\vec{\lambda}_r, \qquad \boldsymbol{G}(s) \triangleq \frac{1}{L}\frac{s}{s+a} \tag{6}$$

where $\Delta\theta = \theta - \hat{\theta}$. Considering (5) and (6), the overall error block diagram is depicted in Fig. 1. The error equation (6) can be further expressed on the estimated rotor frame as:

$$\vec{e}_i' \triangleq e^{-J\hat{\theta}}\vec{e}_i = \begin{bmatrix} e_{\hat{d}} \\ e_{\hat{q}} \end{bmatrix} = \begin{bmatrix} \hat{i}_{\hat{d}} - i_{\hat{d}} \\ \hat{i}_{\hat{q}} - i_{\hat{q}} \end{bmatrix} \cong \boldsymbol{G}'(s)\Delta\theta \boldsymbol{J}\vec{\lambda}_r$$

$$\boldsymbol{G}'(s) = e^{-J\hat{\theta}}\boldsymbol{G}(s)e^{J\hat{\theta}} = \begin{bmatrix} G_{22}'(s) & G_{12}'(s) \\ -G_{12}'(s) & G_{22}'(s) \end{bmatrix} \tag{7}$$

Here $'$ denotes the quantity on the estimated rotor frame. Using (7), the error block diagram in Fig. 1 can be redrawn as shown in Fig. 2, wherein

$$G_{22}'(s) = \frac{1}{L}\frac{s(s+a) + \hat{\omega}^2}{(s+a)^2 + \hat{\omega}^2} \tag{8}$$

Since the closed-loop block diagram in Fig. 2 is linear, the necessary condition for local stability can be derived using Routh-Hurwitz criteria as:

Local stability condition with $\mathbf{K}=k\boldsymbol{I}$:

$$0<\frac{k_I}{k_P}<\frac{R+k}{L} \tag{9}$$

Equation (9) gives the design rule to guarantee local stability so long as the estimation error is small enough. However, under a large estimation error, e.g. during transient, the estimation may become unstable as will be demonstrated later.

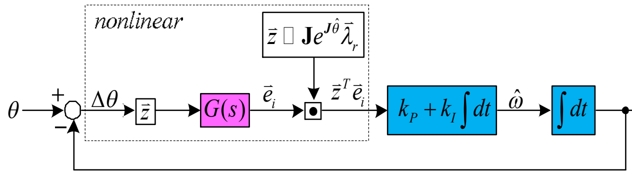


Fig. 1 Estimation error block diagram on the stator reference frame when $\mathbf{K}=k\boldsymbol{I}$.

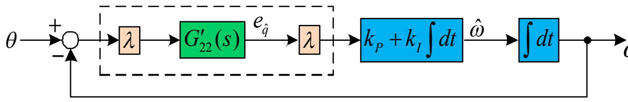


Fig. 2 *Estimation error block diagram on the estimated rotor reference frame when* $\mathbf{K}=k\boldsymbol{I}$.

b) Global stability with $\mathbf{K}=k\boldsymbol{I}-\hat{\omega}L\boldsymbol{J}$

The feedback gain in this case adds a kind of cross coupling term to be $\mathbf{K}=k\boldsymbol{I}-\hat{\omega}L\boldsymbol{J}$. The effect of using this kind of feedback gain is equivalent to eliminating the effect of the inductance voltage in the steady state. The error dynamic becomes simpler than the previous case. The error equation in this case is given by

$$\vec{e}_i=\hat{\vec{i}}-\vec{i}=\frac{1}{L}\left(s\boldsymbol{I}-\hat{\omega}\boldsymbol{J}+a\boldsymbol{I}\right)^{-1}s\left(e^{\boldsymbol{J}\theta}-e^{\boldsymbol{J}\hat{\theta}}\right)\begin{bmatrix}\lambda\\0\end{bmatrix} \tag{10}$$

On the estimated rotor frame, the error equation (10) becomes

$$\vec{e}_i'=\begin{bmatrix}e_{\hat{d}}\\e_{\hat{q}}\end{bmatrix}=\frac{1}{L}(s+a)^{-1}(s\boldsymbol{I}+\hat{\omega}\boldsymbol{J})\left(-\boldsymbol{I}+e^{\boldsymbol{J}(\theta-\hat{\theta})}\right)\begin{bmatrix}\lambda\\0\end{bmatrix} \tag{11}$$

$$\vec{e}_i'=\begin{bmatrix}e_{\hat{d}}\\e_{\hat{q}}\end{bmatrix}=\frac{\lambda}{L}(s+a)^{-1}\begin{bmatrix}-\omega\sin(\theta-\hat{\theta})\\\omega\cos(\theta-\hat{\theta})-\hat{\omega}\end{bmatrix} \tag{12}$$

The d-axis current error $e_{\hat{d}}$ can be used to estimate the rotor position as follows.

Position/Speed estimator II:

$$\left.\begin{aligned}\hat{\omega}&=\left(k_P+k_I\int dt\right)e_{\hat{d}}\\\hat{\theta}&=\int\hat{\omega}dt\end{aligned}\right\} \tag{13}$$

Considering (12) and (13), the overall estimation block diagram can be drawn as shown in Fig. 3.

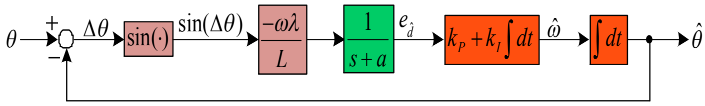


Fig. 3 *Estimation error block diagram on the estimated rotor reference frame when* $\mathbf{K}=k\boldsymbol{I}-\hat{\omega}L\boldsymbol{J}$.

The block diagram in Fig. 3 is almost linear except for the sinusoidal function block. However, the global stability condition of the closed-loop system can be derived using the Lyapunov function method [13][14] as shown in (14). The detailed proof is given in the Appendix B.

Global stability condition with $\mathbf{K}=k\boldsymbol{I}-\hat{\omega}L\boldsymbol{J}$:

$$\hat{\omega}k_P<0,\ \text{ and }\ 0<\frac{k_I}{k_P}<\frac{R+k}{L} \tag{14}$$

To emphasize the importance of the global stability, comparison by simulation results is illustrated in Figs. 4-6. In the simulation, the motor is started by a vector controller with a position sensor, and the estimated position and speed are monitored. The adaptation gains are set rather small in the simulation to intentionally introduce large estimation error during start-up.

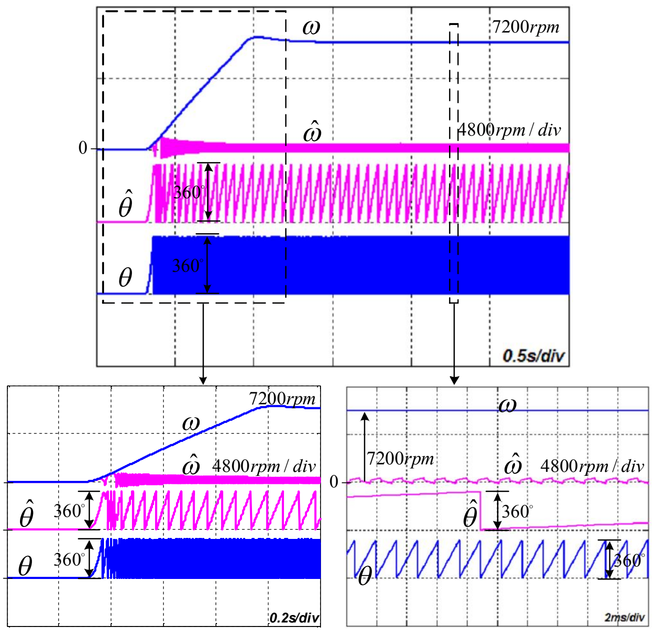


Fig. 4 *Simulation results at start-up for the estimator with* $\mathbf{K}=k\boldsymbol{I}$ *(local stability guaranteed).*

Fig. 4 corresponds to the case with $\mathbf{K}=k\boldsymbol{I}$ by which the estimator is designed for local stability. It is seen that the estimation becomes unstable immediately after starting. On the contrary, Fig. 5 is the case with guaranteed global stability. It can be seen that despite of the large estimation error during start-up the estimator finally converges to the true values as predicted. Fig. 6 gives the results with slowly increasing of speed command from 0 r/min to 3600 r/min to reduce the estimation error during starting. The estimator can work through the starting period without any problem. However, after the estimator reaches the steady-state speed, a large position error is intentionally introduced step-wisely with e_θ = 180 electrical degree. As a result, the estimator with global stability can overcome the large position error and converges, while that with local stability cannot tolerate the large transient error and falls into instability.

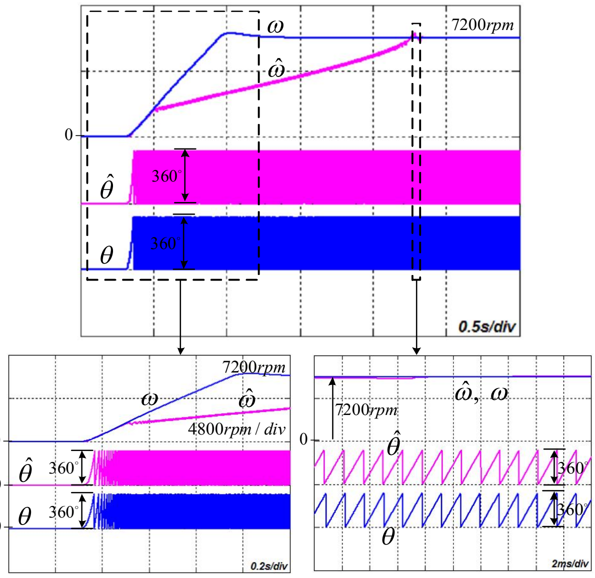
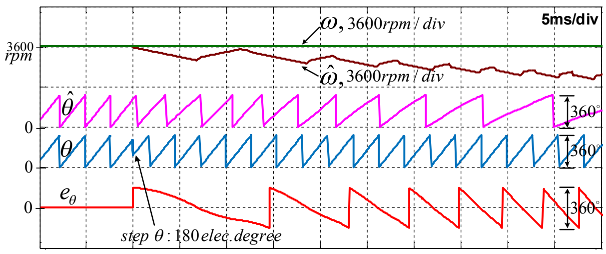
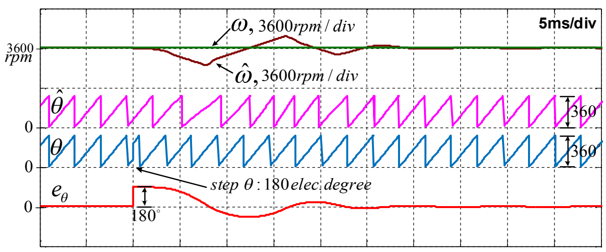


Fig. 5 Simulation results at start-up for the estimator with $\mathbf{K} = k\mathbf{I} - \hat{\omega}L\mathbf{J}$ *(global stability guaranteed).*



(a) Design with local stability: $\mathbf{K} = k\mathbf{I}$



(b) Design with global stability: $\mathbf{K} = k\mathbf{I} - \hat{\omega}L\mathbf{J}$

***Fig. 6** Responses to a large estimator error during the steady-state condition. a)* $\mathbf{K} = k\mathbf{I}$ *b)* $\mathbf{K} = k\mathbf{I} - \hat{\omega}L\mathbf{J}$.

4 TRACKING AND DYNAMIC PERFORMANCES

To design the position and tracking performance of the estimation, it is assumed that the estimation error $\Delta\theta$ is small and $\sin(\Delta\theta) \approx \Delta\theta$. Therefore, the closed-loop transfer function of Fig. 3 is obtained as:

$$\frac{\Delta\theta(s)}{\theta(s)} \approx \frac{s^2(s+a)}{s^3 + as^2 + K's + bK'} \tag{15}$$

where $K' \triangleq -\lambda\omega k_p / L, a \triangleq (R+k)/L, b \triangleq k_I / k_p$

First, the position tracking performance during acceleration/deceleration at rated torque will be investigated. In this situation, the rotor speed will be a ramp function, while the position will be a parabolic one and can be expressed as:

$$\theta(s) = R_\omega / s^3; \quad R_\omega \triangleq p\tau_{rated} / J \tag{16}$$

where R_ω is the acceleration rate at the rated torque τ_{rated}, p is number of pole pairs, and J is the inertia. From the final-value theorem it can be derived that the steady-state error of the position estimation $\Delta\theta_{ss}$ is:

$$\Delta\theta_{ss} = \lim_{s\to 0} s \cdot \frac{s^2(s+a)}{s^3 + as^2 + K's + bK'} \cdot \frac{R_\omega}{s^3} = \frac{aR_\omega}{K'b} = \frac{-aLR_\omega}{\omega\lambda k_I} \tag{17}$$

In other words, for a given tracking error requirement $\Delta\theta_{ss}$ the adaptation integral gain can be calculated as:

$$K' = \frac{aR_\omega}{b\Delta\theta_{ss}} \text{ or } k_I = \frac{-LaR_\omega}{\omega\lambda\Delta\theta_{ss}} \tag{18}$$

To assure a good damping, the design parameters k, k_p, k_I will be chosen so as to obtain the location of all closed-loop poles to be at $-p_0$, i.e.:

$$s^3 + as^2 + K's + bK' = (s + p_0)^3 \tag{19}$$

$$\therefore \quad K' = 3p_0^2, a = 3p_0, b = p_0 / 3 \tag{20}$$

Considering that K' is related to the position tracking performance requirement (18), (19) finally yields the following design rules for tracking and dynamic performances when R_ω and $\Delta\theta_{ss}$ are given:

$$\left.\begin{array}{l} K' = 9R_\omega / \Delta\theta_{ss} \\ p_0 = \sqrt{K'/3} \end{array}\right\} \Rightarrow \left.\begin{array}{l} k_p = -LK' / \lambda\omega \\ k = 3p_0 L - R \\ k_I = k_p p_0 / 3 \end{array}\right\} \tag{21}$$

It should be noted that to achieve the required performances the adaptation proportional gain must be varied inversely with the speed. This is natural because when the speed is low the back induced EMF becomes low too, making the open-loop gain smaller in the low speed range. Therefore, to attain the same tracking performance the adaptation gain must be increased. In practical implementation, a limit must be imposed on the adaptation gain as:

$$k_p = \begin{cases} -LK'/\lambda\omega & \text{for } |\omega| \ge \omega_{\min} \\ -LK'/[\lambda\omega_{\min}\,\mathrm{sgn}(\omega)] & \text{for } |\omega| < \omega_{\min} \end{cases} \tag{22}$$

5 EFFECTS OF PARAMETER VARIATION ON THE ESTIMATION

In this section, the effects of resistance, inductance, and flux variations on the estimation error will be studied. Let the stator resistance and inductance, and the flux linkage used in the estimator be denoted as $\hat{R}, \hat{L}, \hat{\lambda}$, respectively. The observer's equation (3) now becomes

$$\bar{v} = \hat{R}\hat{\bar{i}} + \hat{L}\frac{d\hat{\bar{i}}}{dt} + \frac{d}{dt}\left(e^{J\hat{\theta}}\begin{bmatrix}\hat{\lambda}\\0\end{bmatrix}\right) + \mathbf{K}(\hat{\bar{i}} - \bar{i}) \tag{23}$$

a) Resistance variation

Consider first the case when there is a resistance mismatch $\Delta R = \hat{R} - R$. The estimated current error will then be given by:

$$\begin{aligned} \bar{e}_i &= \boldsymbol{R}(s)\Delta R\bar{i} + \boldsymbol{F}(s)\left(\left(-\boldsymbol{I} + e^{J(\theta-\hat{\theta})}\right)e^{J\hat{\theta}}\begin{bmatrix}\lambda\\0\end{bmatrix}\right) \\ \boldsymbol{R}(s) &= -[L(s\boldsymbol{I} - \hat{\omega}\boldsymbol{J} + a\boldsymbol{I})]^{-1} \\ \boldsymbol{F}(s) &= [L(s\boldsymbol{I} - \hat{\omega}\boldsymbol{J} + a\boldsymbol{I})]^{-1}s \end{aligned} \tag{24}$$

For the steady state condition with $s\boldsymbol{I} = \hat{\omega}\boldsymbol{J}$, the error equation(24) can be further expressed on the estimated rotor frame as:

$$\begin{bmatrix}e_{\hat{d}}\\e_{\hat{q}}\end{bmatrix} = \frac{-\Delta R}{aL}\begin{bmatrix}i_{\hat{d}}\\i_{\hat{q}}\end{bmatrix} + \frac{\lambda}{aL}\begin{bmatrix}-\hat{\omega}\sin(\theta-\hat{\theta})\\\hat{\omega}\cos(\theta-\hat{\theta}) - \hat{\omega}\end{bmatrix} \tag{25}$$

In the steady state, it can be shown from Fig. 3 that if there is no instability the d-axis current error $\hat{e}_d$ will always converge to zero. This will in turn force the estimated rotor speed to converge to the real value, i.e. $\hat{\omega} = \omega$ too, and the position error can be expressed as:

$$(\theta - \hat{\theta}) = \sin^{-1}\left(\frac{-\Delta R}{\lambda\hat{\omega}}i_{\hat{d}}\right) \tag{26}$$

We know that the decoupling control with current control will force $i_{\hat{d}} \approx 0$ as the d-axis current command, and (26) will turn into $\hat{\theta} \approx \theta$. Mean that, the resistance mismatch causes no speed and position error. The simulation result shown in Fig. 7 illustrates the behavior discussed.

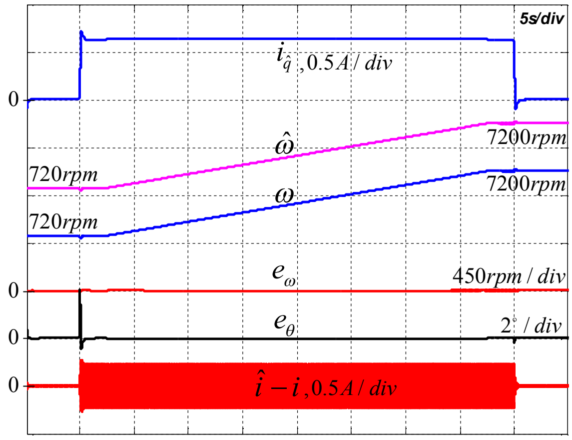


Fig. *7 Simulation result showing effects of stator resistance variation* $\Delta R = -20\%$ *for slowly-swept speed command.*

b) Inductance variation

Similarly, the estimation error in the case of inductance mismatch $\Delta L = \hat{L} - L$ is given by (27).

$$\begin{aligned} \bar{e}_i &= \boldsymbol{L}(s)\Delta L\bar{i} + \boldsymbol{F}(s)\left(\left(-\boldsymbol{I} + e^{J(\theta-\hat{\theta})}\right)e^{J\hat{\theta}}\begin{bmatrix}\lambda\\0\end{bmatrix}\right) \\ \boldsymbol{L}(s) &= \boldsymbol{F}(s) = [L(s\boldsymbol{I} - \hat{\omega}\boldsymbol{J} + a\boldsymbol{I})]^{-1}s \end{aligned} \tag{27}$$

In the steady state with $s\boldsymbol{I} = \hat{\omega}\boldsymbol{J}$, the error equation(27) can be further expressed on the estimated rotor frame as:

$$\begin{bmatrix}e_{\hat{d}}\\e_{\hat{q}}\end{bmatrix} = \frac{\Delta L}{aL}\begin{bmatrix}-\hat{\omega}i_{\hat{q}}\\\hat{\omega}i_{\hat{d}}\end{bmatrix} + \frac{\lambda}{aL}\begin{bmatrix}-\hat{\omega}\sin(\theta-\hat{\theta})\\\hat{\omega}\cos(\theta-\hat{\theta}) - \hat{\omega}\end{bmatrix} \tag{28}$$

With the d-axis current error converge to zero, the position error can be expressed as:

$$(\theta - \hat{\theta}) = \sin^{-1}\left(\frac{-\Delta L}{\lambda}i_{\hat{q}}\right) \tag{29}$$

Noticed that, the estimated position will contain some error depending on load but independent of the rotor speed since the magnitude of the transfer function *L(s)* in the steady state is not a function of the rotor speed. From the simulation result in Fig. 8, it is noted that inductance mismatch only causes no speed error and very small position and current errors, independent of the rotor speed.

c) Flux linkage mismatch

In the case of flux linkage error $\Delta\lambda = \hat{\lambda} - \lambda$, the estimated current error is given by (30).

$$\begin{aligned} \bar{e}_i &= \boldsymbol{H}(s)e^{J\hat{\theta}}\begin{bmatrix}\Delta\lambda\\0\end{bmatrix} + \boldsymbol{F}(s)\left(\left(-\boldsymbol{I} + e^{J(\theta-\hat{\theta})}\right)e^{J\hat{\theta}}\begin{bmatrix}\lambda\\0\end{bmatrix}\right) \\ \boldsymbol{H}(s) &= \boldsymbol{F}(s) = [L(s\boldsymbol{I} - \hat{\omega}\boldsymbol{J} + a\boldsymbol{I})]^{-1}s \end{aligned} \tag{30}$$

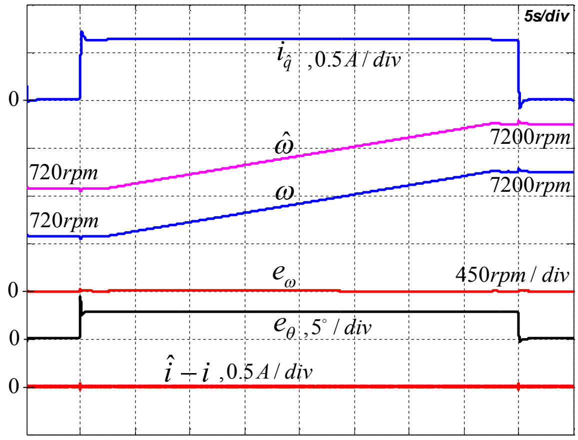


Fig. 8 Simulation result showing effects of stator inductance variation $\Delta L = -20\%$ for slowly-swept speed command.

In the steady state with $s\boldsymbol{I} = \hat{\omega}\boldsymbol{J}$, the error equation(30) can be further expressed on the estimated rotor frame as:

$$\begin{bmatrix} e_{\hat{d}} \\ e_{\hat{q}} \end{bmatrix} = \frac{\Delta\lambda}{aL}\begin{bmatrix} -\hat{\omega}\sin(\theta-\hat{\theta}) \\ \hat{\omega}\cos(\theta-\hat{\theta}) \end{bmatrix} + \frac{\lambda}{aL}\begin{bmatrix} -\hat{\omega}\sin(\theta-\hat{\theta}) \\ \hat{\omega}\cos(\theta-\hat{\theta})-\hat{\omega} \end{bmatrix} \quad (31)$$

With the d-axis current error converge to zero, it will in turn force the estimated rotor position to converge to the real value, i.e. $\hat{\theta} = \theta$ too, and the q-axis current error can be expressed as:

$$e_{\hat{q}} = \frac{\Delta\lambda}{aL}\hat{\omega} \quad (32)$$

Mean that, flux linkage error produces neither position nor speed error in the steady state, just only cause the q-axis current error increase with speed. Simulation result in Fig. 9 reveals that flux linkage error produces neither position nor speed error in the steady state.

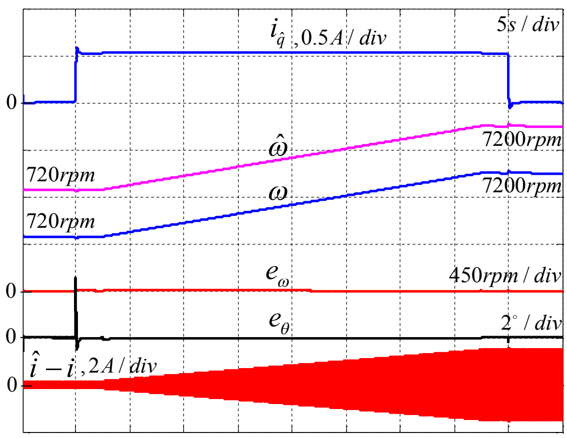


Fig. 9 Simulation result showing effects of rotor flux variation $\Delta\lambda = -20\%$ for slowly-swept speed command.

In summary, the proposed estimator is very robust against parameter variations, especially the resistance and the rotor flux.

6 EXPERIMENT RESULTS AND DISCUSSION

The proposed estimator based on the reduced-order model and block diagram of the experimental set up are implemented as shown in Fig. 10 and 11 respectively. The spindle motor of a hard disk is connected to the dc servo motor which acts as a load. Motor parameters are given in the Appendix A. The estimator is designed with tracking error during acceleration around 5 degrees.

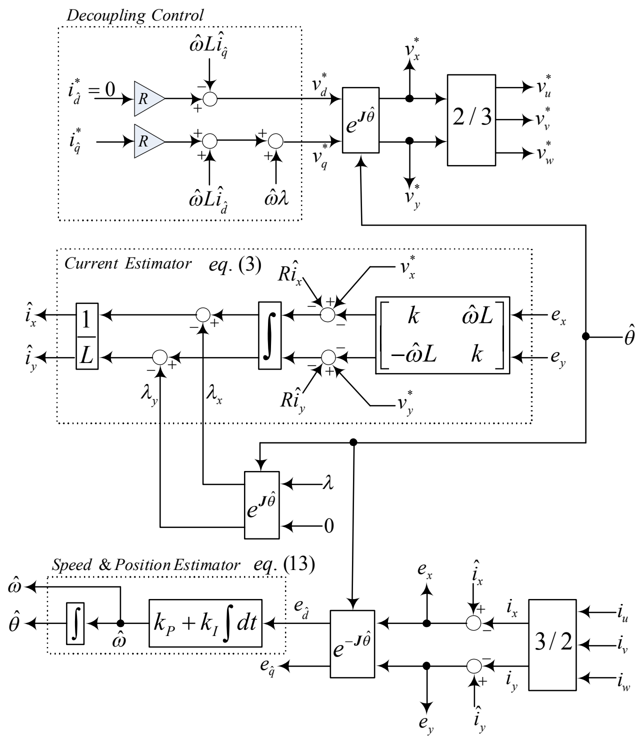


Fig. 10 Block diagram of the proposed sensorless vector controller.

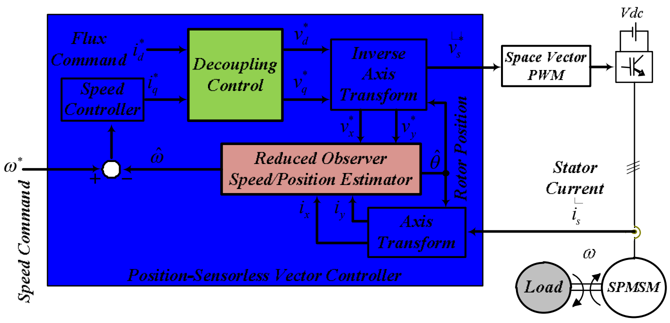
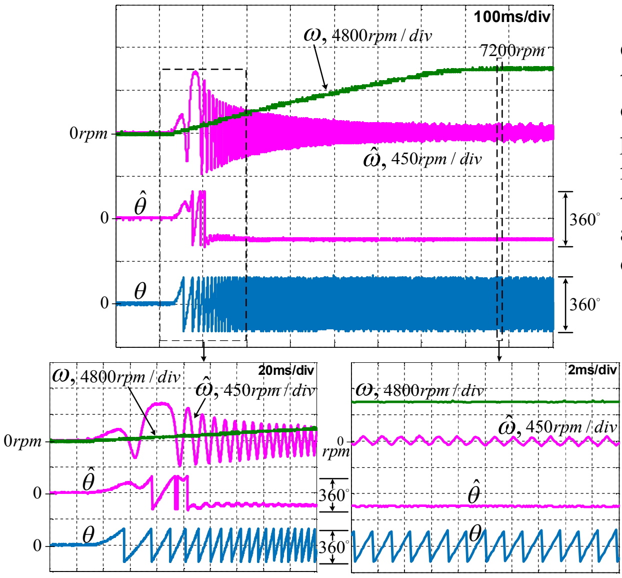
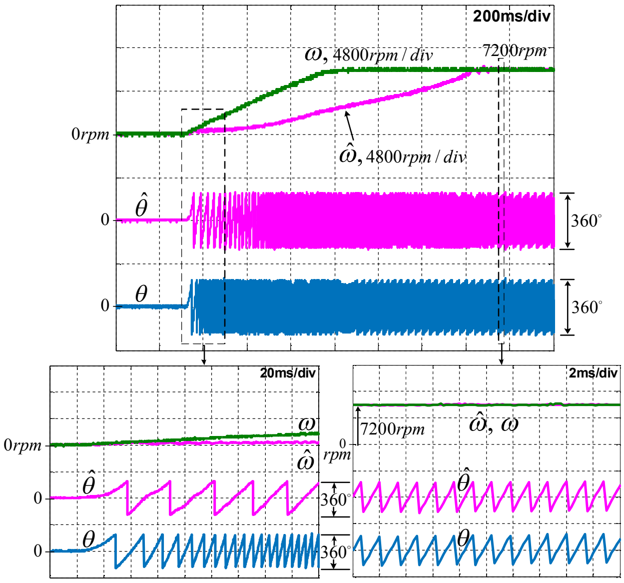


Fig. 11 Position sensorless drive based on the proposed estimator.



(a) *Design with local stability:* $\mathbf{K} = k\boldsymbol{I}$



(b) *Design with global stability:* $\mathbf{K} = k\boldsymbol{I} - \hat{\omega}L\boldsymbol{J}$

Fig. 12 *Experimental result at starting with low adaptation gains for comparison of local and global stability property.*

To verify the analysis result on stability, the vector controller uses the real position information from the encoder in control while all the estimated values are just for monitoring. Fig. 12(a) is starting operation with only local stability, i.e. $\mathbf{K} = k\boldsymbol{I}$. Similar to the simulation result in Fig. 4, the estimation becomes unstable shortly after starting. On the contrary, Fig. 12(b) is the same operation with global stability, $\mathbf{K} = k\boldsymbol{I} - \hat{\omega}L\boldsymbol{J}$. Even though there is a large estimation error in the beginning, the estimation finally converges in a similar manner as the simulation result in Fig. 5.

Sensorless drive system is then tested under several conditions as shown in Figs. 13-18. It can be seen that the sensorless drive system works stably under all operating conditions. There can be seen some small position estimation error when the motor is loaded. This may come from the parameter mismatches explained in the previous section. It should be noted however that in all cases the estimated speed is always correct as pointed out in Section V.

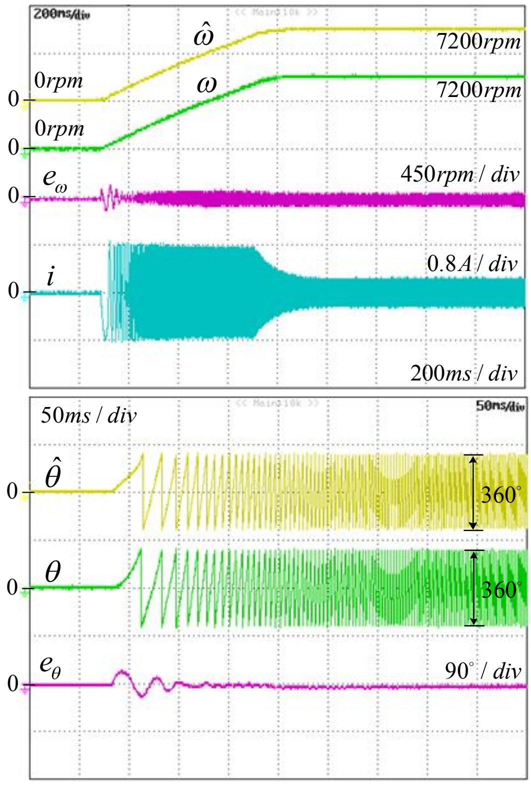
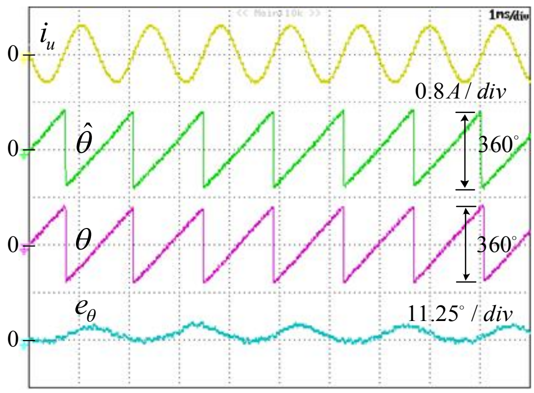
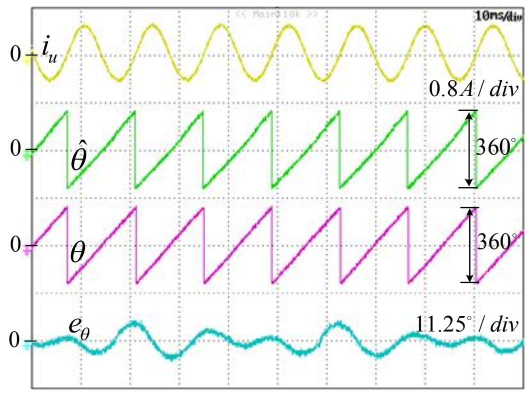


Fig. 13 *Experimental result at starting to the rated speed.*



(a) 7200 rpm

Fig. 14 *Experimental result for steady-state operations under rated load at 7200 rpm and 720 rpm. (cont.)*



(b) 720 rpm

***Fig. 14** Experimental result for steady-state operations under rated load at 7200 rpm and 720 rpm.*

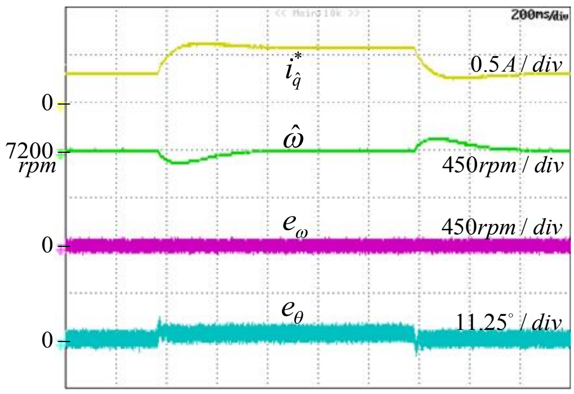


***Fig. 15** Experimental result showing step-load response at 7200 rpm.*

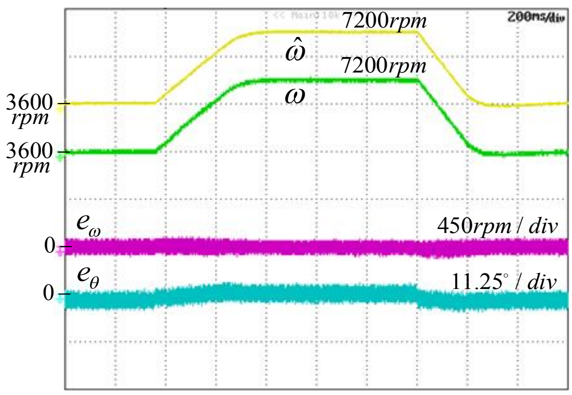


***Fig. 16** Experimental result at acceleration/deceleration.*

7 CONCLUSION

From the physical insight of the SPMSM's winding voltage, a new reduced-order model is introduced in this paper. The proposed model is simple, contains only the rotor position as a parameter, and has all the variables known or measurable. Based on the proposed model, a globally stable estimator is constructed. The importance of global stability is clearly illustrated by comparison with the case of local stability. Design criteria for tracking and dynamic performances of the estimation are then given to assure stable and satisfied response of the sensorless drive. All the analytical results are verified by simulation and experiment.

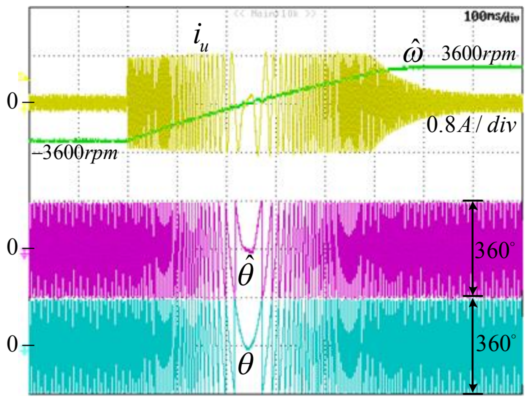


***Fig. 17** Experimental result at speed reversal.*

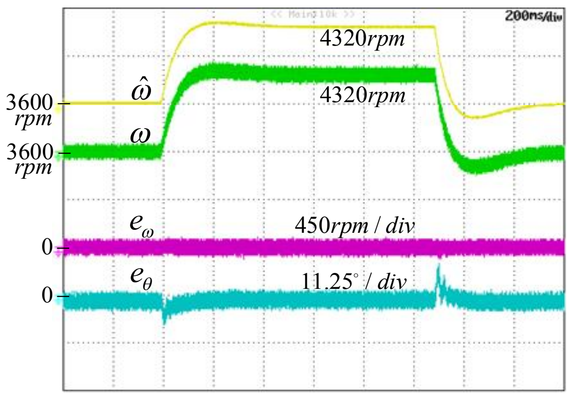


***Fig. 18** Experimental result showing small-step speed response.*

Appendix

A. Motor's parameters

rated speed	7200 *rpm*
rated torque	4.14 *mNm*
rated current	1.25 *A*
pole pairs (p_p)	6
flux linkage (λ)	1.101 *mWb*
stator resistance (R)	1.743 Ω
stator inductance (L)	0.426 *mH*
motor inertia (J)	4.28×10^{-6} $kg \cdot m^2$

B. Proof of global stability of the estimator

First, the error block diagram in Fig. 3 is redrawn as shown in Fig. B1. Considering the case where the rotor speed is constant, the state variables in the block diagram will satisfy the following relationship.

$$\left.\begin{aligned} y &\triangleq y' + \omega \\ \dot{\hat{\theta}} &= \hat{\omega} = x + y = x + y' + \omega \\ \dot{x} &= K'\sin(\Delta\theta) - ax \\ \dot{y} &= \dot{y}' = bx \\ \Delta\dot{\theta} &= \dot{\theta} - \dot{\hat{\theta}} = \omega - \dot{\hat{\theta}} = -x - y' \end{aligned}\right\} \quad (33)$$

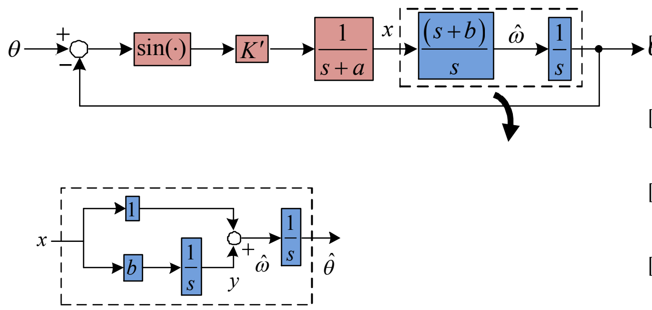


***Fig. B1**. Estimation error block diagram redrawn.*

Let the Lyapunov function be defined as:

$$\left.\begin{aligned} V &\triangleq \int_0^{\Delta\theta} \sin(\sigma)d\sigma + \frac{1}{2}[x \quad y']\boldsymbol{P}\begin{bmatrix} x \\ y' \end{bmatrix} \\ \boldsymbol{P} &\triangleq \begin{bmatrix} P_{11} & P_{12} \\ P_{12} & P_{22} \end{bmatrix} > 0 \end{aligned}\right\} \quad (34)$$

Using (33) it can be derived that

$$\begin{aligned} \dot{V} &= \sin(\Delta\theta)\Delta\dot{\theta} + [x \quad y']\begin{bmatrix} p_{11} & p_{12} \\ p_{12} & p_{22} \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{y}' \end{bmatrix} \\ &= x^2[p_{12}b - p_{11}a] + x\sin(\Delta\theta)[p_{11}K' - 1] \\ &\quad + y'\sin(\Delta\theta)[p_{12}K' - 1] + y'x[p_{22}b - p_{12}a] \end{aligned} \quad (35)$$

Therefore, if the following conditions are satisfied,

$$\left.\begin{aligned} &K' > 0, \quad p_{12}b - p_{11}a < 0, \\ &p_{11}K' - 1 = 0, \quad p_{12}K' - 1 = 0, \quad p_{22}b - p_{12}a = 0 \end{aligned}\right\} \quad (36)$$

Then

$$\dot{V} = -\frac{(a-b)}{K'}x^2 \le 0, \text{ and } \boldsymbol{P} > 0 \quad (37)$$

Therefore, $x(t) \to 0$ and $\dot{V} \to 0$. From (27), it can be shown that $x(t) \equiv 0$ implies $y'(t) \equiv \Delta\theta(t) \equiv 0$. Lasalle's Theorem can be then used to conclude the stability [13][14], and the stability condition (14) is derived from the inequalities in (36).

REFERENCES

[1] N. Matsui et al., "A new sensorless drive of brushless dc motor," Proc. of IECON 1992, pp. 430-435.

[2] G. Yang, R. Tomioka, M. Nakano, and T. H. Chin, "Position and speed sensorless control of brushless DC motor based on an adaptive observer," IEEJ Trans. Ind. Appl. No. 113, 1993, pp. 579–586.

[3] S. Po-ngam and S. Sangwongwanich, "Stability and Dynamic Performance Improvement of Adaptive Full-Order Observers for Sensorless PMSM Drive," IEEE Trans. Power Elec., vol. 27, no. 2, pp. 588-600, 2012.

[4] R. Ortega et al., "Estimation of Rotor Position and Speed of Permanent Magnet Synchronous Motors With Guaranteed Stability," IEEE Trans. Control Systems Technology, vol. 19, no. 3, pp. 601-614, 2011.

[5] S. Shinnaka, "New "D-State-Observer" Based Sensorless Vector Control for Permanent Magnet Synchronous Motors," IEEE IAS Annual Meeting 2004, pp. 1000-1007.

[6] B. Nahid Mobarakeh, F. Meibody-Tabar, and F.M. Sargos, "Robustness Study of a Model-Based Technique for Mechanical Sensorless PMSM," Proc. of IEEE PESC'01 (2001), pp. 811–816.

[7] A. Piippo, M. Hinkkanen, and J. Luomi, "Analysis of an adaptive observer for sensorless control of PMSM drives," Conf. Rec of IEEE-IECON Annu. Meeting (2005).

[8] J. S. Kim and S. Sul, "High performance PMSM drives without rotational position sensors using reduced order observer.," Conf. Rec of IEEE-IAS Annu. Meeting 1 (1995), pp. 75 - 82.

[9] M. Tomita, T. Senjyu, S. Doki, and S. Okuma, "New sensorless control for brushless DC motors using disturbance observers and adaptive velocity estimation" IEEE Trans. Ind. Elec., vol. 45, no. 2 (2006), pp. 274-282.

[10] J. Solsona, M. Valla, and C. Muravchik. Nonlinear Reduced Order Observer for Permanent Magnet Synchronous Motors. IEEE Trans. Ind. Electron., vo. 43, no. 4 (1996), pp. 492–497.

[11] K. Tatematsu, D. Hamada, K. Uchida, S. Wakao, and T. Onuki. Sensorless control for permanent magnet synchronous motor with reduced order observer. Proc. of IEEE PESC'98 (1998), pp. 125–131.

[12] L. A. Jones, and J. H. Lang. A state observer for the permanent-magnet synchronous motor. IEEE Trans. Ind. Electron., vol. 36, no. 4 (1989), pp. 346–354.

[13] D. Y. Abramovitch, "Analysis and design of a third order phase-lock loop," in Proceedings of the IEEE Military Communications Conference, vol. 2, pp. 455-459, 1988.

[14] D. Y. Abramovitch, "Lyapunov redesign of analog phase-lock loops," IEEE Trans. Comm., vol. 38, no. 12 (1990), pp. 2197-2202.

Prachuab Iamsamang was born in Prachuapkhirikhan, Thailand, in 1975. He received the B.Eng. degree in electrical engineering from South-East Asia University, Bangkok, Thailand, in 1997, and the M.Eng. degree in electrical engineering from Chulalongkorn University, Bangkok, Thailand, in 2003, where he is currently working toward the Ph.D. degree in electrical engineering. He is currently a Officer in the Research & Development Department of Novem Engineering Co.,Ltd. His present interests are in the areas of sensorless control of synchronous machines.

Somboon Sangwongwanich (S'88–M'90) was born in Bangkok, Thailand, in 1962. He received the B.Eng, M.Eng., and Dr. Eng. degrees from Nagoya University, Nagoya, Japan, in 1985, 1987, and 1990, respectively, all in electrical engineering. He is currently an Assistant Professor in the Department of Electrical Engineering, Chulalongkorn University, Bangkok, Thailand. His research include sensorless control of ac machines, EMI filters, and power converters. Dr. Sangwongwanich has received several Prize Paper Awards from the IEEE, the Institute of Electrical Engineers of Japan, and the Society of Instrument and Control Engineers of Japan.

ANN Application for Solar Radiation Forecasting using Levenberg-Marquardt Algorithm

Boonyang Plangklang and **Jakrapan Nantaphunkul**

Manuscript received November 5, 2015
Revised November 30, 2015

ABSTRACT

The most significant limitation of PV power output is the uncertainty of radiation. This will mainly affect the quality of the electrical grid system. For this reason, artificial neural network (ANN) has been used for several years for forecasting and integrating in PV energy management to improve PV systems. In this paper, the learning property of ANN was applied to forecast solar radiation. Levenberg-Marquardt optimization technique was used as a back propagation algorithm for the Multilayer Feed Forward model. It is formed and supervised learning algorithm. The radiation values from Homer program was used as training data. The output of the proposed ANN is compared with output from Homer Program in a day ahead. From the results it showed that ANN with Log-Sigmoid Function in 1st, 2nd hidden layer and Pure linear Function (5-2-1) in output layer have the lowest annual average forecasting error at 4.60%.

Keywords: *Forecasting, Artificial Neural Network, Solar Radiation*

1 INTRODUCTION

Nowadays photovoltaic systems have been increasingly installed worldwide in recent years. Because it produces clean energy, moreover the technology is continuously developed therefore the reliability is increasing but the price is decreasing in opposite. The most significant limitation of PV system is the uncertainty of power from the sun. This will affect the quality of the electrical power system. The forecasting system was applied to implement the solar radiation [1]. The study must select appropriate input data, pattern of input that affect the output [2]. This paper will present the forecasting of solar radiation by calculating the solar radiation and collecting data from weather forecasting. The solar radiation from the Homer program was used as an adaptive architecture to forecast.

Boonyang Plangklang and Jakrapan Nantaphunkul are with the Department of electrical engineering, Faculty of Engineering, 39 Moo 1, Rangsit- Nakhonnayok Road, Thanyaburi, Pathum Thani 12110 (email: boonyang.p@en.rmutt.ac.th)

2 THEORETICAL BACKGROUND

2.1 Solar Radiation by Homer program

HOMER software has been used as the solar resource inputs. HOMER can deliver the radiation values simply by inputting latitude location to calculation the daily radiation.

In case study, we used the time zone GMT+07:00 Krasnoyarsk, Thailand, Laos, Vietnam. The scale annual average is 5 kWh/m^2/d. The software can export the data to apply for the forecasting system as show figure 1.

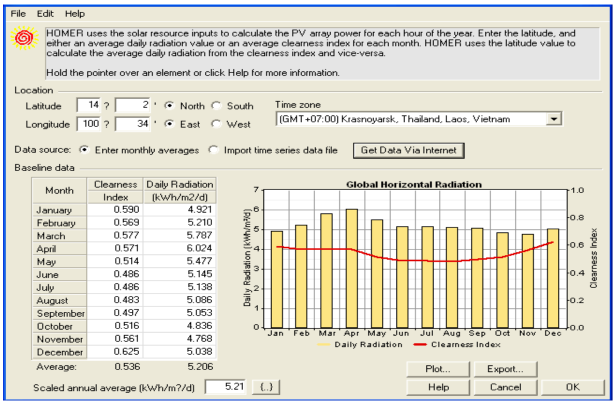


Fig. 1*. Feature of Radiation values from Homer Program.*

2.2 Artificial Neural Network

The Back Propagation algorithm commonly is an input layer, Hidden layer, Output layer of each layer will send signal to all neural, In connection with the International Neural be adjusted, this is called the weight and the Bias through to transformer function.

When a data into input have a number **R**, network data will be multiplied by the weight from each of Information by multiplying each of Neural and compared with the targets set.

The adjusted weighted will be trained with Levenberg-Marquardt algorithm method [3], the working principles are shown as followings.

2.2.1 Profile of Sum square error (SSE)

This is considered an error during training and configuring output data as shown in equation (1).

$$E(x,w) = \frac{1}{2}\sum_{p=1}^{P}\sum_{m=1}^{M} e_{p,m}^2 \tag{1}$$

By x = Vector input data
w = Vector weighted adjust
P = Input layer $1 - P$,P is input data
M = Output layer $1 - M$, M is output data
$e_{p,m}$ = Dislocation of output layer from training m
Compared with the input data, p

$$e_{p,m} = d_{p,m} - o_{p,m} \tag{2}$$

By d = Vector output data as assigned.
o = Vector output from the training

2.2.2 Calculation method Jacobian matrix

Consider network j layer for each input ni ,then it is the output $y_{j,i}$ the output of each neural j Can be calculated as shown in Equation (3)

$$y_j = f_j\ (net_j) \tag{3}$$

By f_j = Activation function neural J
net_j = Output weighted J

$$net_j = \sum_{i=1}^{ni} w_{j,i}\, y_{j,i} + w_{j,0} \tag{4}$$

And $y_{j,i}$ = Weight nerve ($w_{j,i}$) of each neural at J
$w_{j,0}$ = The bias Neural at J

2.2.3 Training and adjusted weighted method.

The process of adjusting the weighted method of Levenberg-Marquardt Algorithm is to manage equation by follow relation between Hessian matrix H and Jacobian matrix J together with Gauss-Newton algorithm as show in equation 5

$$w_{k+1} = w_k - (J_k^T J_k + uI\,)^{-1} J_k e_k \tag{5}$$

Training process is to switch between Steepest descent algorithm and Gauss-Newton algorithm By considering the coefficient u ,the smaller it is so close to zero Gauss-Newton algorithm will be considered in the equation 6.

$$w_{k+1} = w_k - (J_k^T J_k\,)^{-1} J_k e_k \tag{6}$$

And coefficient u that very large steepest descent algorithm will be considered in the equation (7).

$$w_{k+1} = w_k - \alpha g_k \tag{7}$$

Considering coefficient u if still very large, can be adjust α as in equation (8).

$$\alpha = \frac{1}{\mu} \tag{8}$$

Step backward diffusion method will be apply the rule to adjust of each pattern (Pattern-by-Pattern Updating Rule) to adjust the weighting links within the network ,to matching input and targets to get learning network in equation (9).

$$\{P_1, t_1\}, \{P_2, t_2\}, \{P_3, t_3\}, \dots, \{P_n, t_n\} \tag{9}$$

The trainer neural networks by repeat N times, it said that network links had been training to first round (Epoch) with this feature neural network can be remembered data in a sequence of events.

In this paper used Neural Network toolbox MATLAB [5] to training Levenberg-Marquardt (trainlm) model to trial with transfer function (tan-sigmoid, log-sigmoid, purelin).

To find an error that Mean Absolute Percent Error (MAPE) lowest. Neural network of each forecast it consist of input layer 1 layer, ganglion equal with number of series and hidden layer 2 layer ,number of ganglion is depend on design output layer have 1layer as shown in Figure2 .

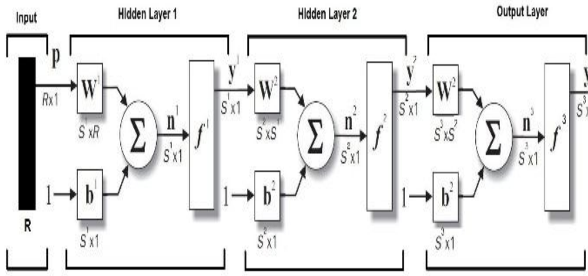


Fig. 2 *Neural networks used for forecasting.*

2.3 VARIABLE SELECTION OF TRAINING DATA

To select variables for forecasting, we use the amount of solar radiation an hourly since 0:00 -23 :00 from HOMER program as shown in Figure 3.

Date	End Time	Solar Radiation (kW/m2)	Incident Solar (kW/m2)	PV Power (kW)	Grid Purchases (kW)	Grid Sales (kW)	Excess Electricity (kW)	Inverter Input (kW)	Inverter Output (kW)	Rectifier Input (kW)	Rectifier Output (kW)
Jan 1	1:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	2:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	3:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	4:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	5:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	6:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	7:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	8:00	0.07	0.06	0.47	0.00	0.46	0.000	0.47	0.46	0.00	0.00
Jan 1	9:00	0.14	0.12	0.95	0.00	0.92	-0.000	0.95	0.92	0.00	0.00
Jan 1	10:00	0.25	0.24	1.79	0.00	1.74	-0.000	1.79	1.74	0.00	0.00
Jan 1	11:00	0.05	0.05	0.36	0.00	0.35	-0.000	0.36	0.35	0.00	0.00
Jan 1	12:00	0.04	0.04	0.27	0.00	0.26	-0.000	0.27	0.26	0.00	0.00
Jan 1	13:00	0.25	0.23	1.73	0.00	1.68	0.000	1.73	1.68	0.00	0.00
Jan 1	14:00	0.22	0.20	1.50	0.00	1.46	0.000	1.50	1.46	0.00	0.00
Jan 1	15:00	0.09	0.08	0.60	0.00	0.59	0.000	0.60	0.59	0.00	0.00
Jan 1	16:00	0.05	0.04	0.33	0.00	0.32	-0.000	0.33	0.32	0.00	0.00
Jan 1	17:00	0.09	0.09	0.65	0.00	0.63	0.000	0.65	0.63	0.00	0.00
Jan 1	18:00	0.03	0.03	0.26	0.00	0.25	-0.000	0.26	0.25	0.00	0.00
Jan 1	19:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	20:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	21:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	22:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 1	23:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 2	0:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00
Jan 2	1:00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.00

Fig. 3 *Example of Solar Radiation data from Homer program (up to one year).*

All data will be used to train neural network and we will used the data on the last day for testing the proposed neural. The defined data sets of input are as shown in Table1 .

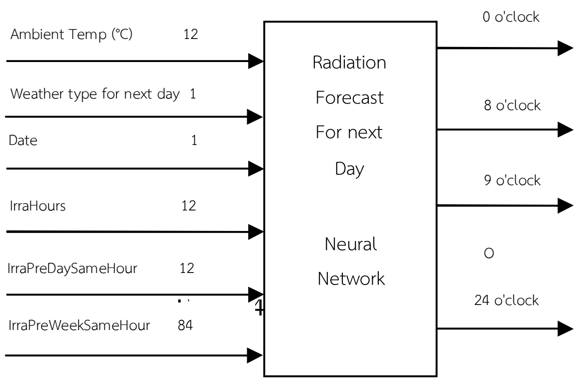
***Table 1** Input data learning.*

Data Learning	Amount
Hour	1
The next day the sky	1
The hourly temperature (in forecasting day) Ambient Temp (°C)	24
Solar hourly(in forecasting day)	24
Solar hourly before forecasting 1 day	24
Solar hourly before forecasting before1week.	168

Data of sky condition in the next day is defined as following [2]. The proposed ANN is as Fig. 4.

***Table 2** Import data learning.*

Order	Forecasting	Clear sky index
1	Clear sky, Partly cloudy	0.9
2	Mostly cloudy	0.6
3	Raining, Fog	0.3



2.4 TRAINING

To create and train the neural network, the program MATLAB is used. The last 7 days solar data from homer is used for testing neural network. The mean absolute percentage Error (MAPE) is used to investigate the error as equation (1(0.

$$MAPE = \frac{100}{N}\sum_{i=1}^{n}\left[\frac{\left|P_f^i - P_a^i\right|}{P_a^i}\right]\% \qquad (10)$$

From the training experiments, the average errors in forecasting of the neural network in hidden layer 1 and hidden layer 2 are shown in table 3.

3 EXPERIMENT RESULTS

The results after testing the neural network, the best value was carried out by hidden layer (Log- sigmoid) and output function (Pure linear) which has a lowest error. The forecasting output in a day ahead is shown in Fig. 5.

***Table3** Forecasting outputs and errors.*

Hidden layer1	Hidden layer 2	Output layer	Amount of neural	MAPE (%)
radbas	logsig	purelin	4-6-1	17.31
radbas	radbas	purelin	1-4-5	36.26
radbas	tansig	purelin	1-4-7	10.96
radbas	purelin	purelin	1-5-6	12.99
tansig	logsig	purelin	1-6-2	35.76
tansig	radbas	purelin	1-5-2	24.54
tansig	tansig	purelin	1-3-8	36.76
tansig	purelin	purelin	1-5-4	70.23
logsig	logsig	purelin	1-2-5	4.60
logsig	radbas	purelin	1-5-8	21.54
logsig	tansig	purelin	1-4-10	37.06
logsig	purelin	purelin	1-5-8	11.54
purelin	logsig	purelin	1-4-9	30.35
purelin	radbas	purelin	1-5-10	68.17
purelin	logsig	purelin	1-2-4	16.69

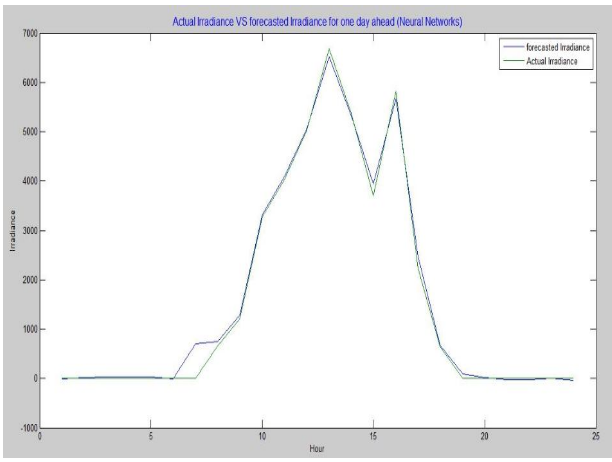


***Fig. 5** Forecasting result for 1 day ahead.*

4 CONCLUSION

The Levenberg-Marquardt Algorithm was used for solar radiation forecasting. The radiation data input for neural network back propagation from Homer program was used. The result showed that the proposed forecasting neural network with Log-Sigmoid Function of hidden layer 1 and Pure-linear Function of hidden layer 2, had and output error value (MAPE) at 4.60%. This can confirm that the proposed ANN is able to implement for solar radiation system.

REFERENCES

[1] Cai Tao, Duan Shanxu and Chen Changsong. "Forecasting Power Output for Grid-Connected Photovoltaic Power System without using Solar Radiation Measurement" Power Electronics for Distributed Generation Systems (PEDG), 2010 2nd IEEE

International Symposium on Digital Object Identifier: 10.1109/PEDG.2010.5545754 Publication Year: 2010 , Page(s): 773 – 777

[2] C.Chupong and B.Plangklang , “Forecasting power output of PV grid connected in Thailand without using solar radiation measurement”, The 9th Eco-Energy and Materials Science and Engineering Symposium, May 25-28 2011

[3] A. Yona, T. Senjyu, and T. Funabashi, "Application of recurrent neural network to short-term-ahead generating power forecasting for photovoltaic system," 2007 IEEE Power Engineering Society General Meeting, Vols 1-10, pp. 3659-3664, 2007

[4] Mellit A., Arab A.H., Khorissi N., Salhi H, “an ANIF based forecasting for solar radiation data from sunshine duration and ambient temperature” Power Engineering Society General Meeting,2007. IEEEDigital Object Identifier:10.1109/PES.2007.38631 Publication Year: 2007, Page(s): 1 – 6

[5] H. Demuth and M.Beale, *Neural Network*, March 2001.

[6] V.V Phansalkar and P.S. Sastry, Analysis of the back-propagation algorithm with momentum, *IEEE Transactions on Neural Network*, 5(3), 505-506, March 1994.

[7] Christiaanse,.W.R. “Short-term load forecasting using exponential smoothing” *IEEE Trans.Power Appar.Syst.*PAS-90(1971) : 900-910

[8] M. T. Hagan, “Training Feedforward Networks with Marquardt Algorithm,” *IEEE Trans. on Neural Networks*, vol.6, pp 989-993, 1994.

Boonyang Plangklang received the Dr.-Ing. from University of Kassel, Germany in 2005. His research interests include Hybrid Renewable Energy. Now he is an instructor in Dept. of Electrical Engineering, Faculty of Engineering, of Rajamangala University of Technology Thanyaburi Thailand.

Jakrapan Nantaphunkul received the Bachelor’s Degree of Engineering, Major Electrical Engineering from Rajamangala University of Technology Thunyaburi, Thailand in 2008. His research interests include research interests include Hybrid Renewable Energy.

Design and Implementation of High Speed 1024-point FFT Using FPGA: An Application for High Speed OFDM Communication Systems

Kidsanapong Puntsri

Manuscript received November 12, 2015
Revised December 4, 2015

ABSTRACT

This work presents a design and implementation of high speed Fast Fourier transform (FFT) processing using a field programmable gate arrays (FPGA). The design is aimed for using in high speed OFDM receiver. The FFT-size of 1024-point is considered. To meet a high speed FFT computation, four-parallel of Radix-4 are used as a calculation topology. Therefore, 16-parallel input are calculated at the same time for each stage. Additionally, 64-quadrature amplitude modulation (QAM) demapping at the update rate of analog-to-digital (ADC) of 400 Msps is considered. The total data rate of 2.4 Gbps can be achieved. To verify the proposed processes, all units are realtime calculated in FPGA. Bit error is evaluated and its output is fed into an oscilloscope for realtime measurement. The ML605 virtex-6 EVM board is used for this implementation and the number of resources usage is moderate. The computation showed that it is well agreed with Matlab, which is precalculated in off-line.

Keywords: *Orthogonal frequency division multiplexing; field programmable gate arrays; Radix-4;*

1. INTRODUCTION

Nowadays, orthogonal frequency division multiplexing (OFDM) plays an importance role for both wire and wireless communication systems. OFDM has many advantages when compared with single carrier communication systems (SCCS). It well combat intersymbol interference (ISI) by appending cyclic prefix (CP) unit into the front of each OFDM symbol. In addition, OFDM also has selective-frequency attenuation, which means that only some subcarriers are destroyed while the rest are not. If orthogonally is maintained, each subcarrier is independently to each other. Unlike SCCS, if the carrier is crashed, the whole carrier will be completely lost. As a result, for OFDM, a high *M-ary* quadrature amplitude modulation (QAM) mapping can be offered; then, high spectrum efficiency and capacity can be achieved.

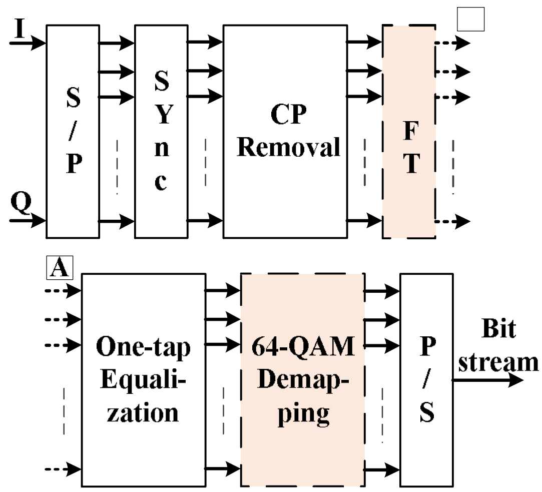


Fig. 1 The receiver block diagram of OFDM communication systems: the dotted line boxes are considered in this work.

OFDM is already put into many communication standards [1]. Especially, in broadband communications, OFDM is mostly used as a modulator, there is very highly active in both theoretical research and implementation development, such as long term evolution (LTE) [2] and multi-gigabit OFDM [3] in 3gpp project. However, this work is focused on only an implementation of Fast Fourier transform (FFT) processing and 64-QAM demapping for broadband multi-gigabit OFDM communication systems mode. Generally, the multi-gigabit OFDM operate at 60 GHz [3]. The FFT/Invert FFT (IFFT) is the main processing unit for OFDM modulation format and it is very challenge unit for researchers to make it works in the practical communication systems. Most of the realtime implementations of communication systems have been realized by using field programmable gate arrays (FPGA) which is used as a digital signal processing (DSP) process. In [4] had been proposed FPGA implementation of 228 Mbps throughput with the FFT-size of 64 point and 16-QAM mapping are employed. C. Dick [5] and J. Garcia [6] had discussed and demonstrated that the FPGA implementation for OFDM communication systems. 64-point FFT had been used. However, the designed is based-on the design suite

Kidsanapong Puntsri is with the Next generation of broadband communications laboratory, Department of Electronics and Telecommunication Engineering, Faculty of Engineering, Rajamangala University of Technology Isan, Khonkhean Campus, Khon Khean, Thailand (email: kidsanapong.pu@rmuti.ac.th)

software which is not so flexible to implement for any DSP algorithms that are not or higher than standardizations. As can be seen that the implementation of FFT for OFDM keeps moving forward. However, the FFT size and the speed of computation for wireless communication systems are still low.

A. Mecwan and D. Shah [7] has been presented that the design of 64-point FFT and IFFT for OFDM transceiver. Those of them are the main processing modules. However, all modules are designed using System Generator in MATLAB2010a which is not so efficient to debug and modify the algorithms. The implementation is based on Virtex 5 series of FPGAs.
The FFT size and speed are still low in the market. In this work, a base band high speed FFT design and implementation are proposed for wideband mode of high speed OFDM communication systems. The FFT-size of 1024 with 64-QAM mapping is employed. The implementation is based-on a Virtex-6 ML605 evaluation board (EVM). The target of the analog-to-digital (ADC) sampling clock or update rate is 400 MHz. Four-parallel Radix-4 processing is used. As a result, 2.4 Gbps (=6 bits x400) of calculation throughput is achieved where the internal clock is only 50 MHz. The basic OFDM receiver block diagram is shown in Fig. 1. However, the considered implementation units are included only the FFT and 64-QAM demapping processing which are shown in the doted-line. This work is selected to be extended one by the 38th Electrical Engineering Conference (EECON-38) and the work from [8] .

The rest of this organized as follow: in section 2, hardware constrains is discussed where the targets are clarified to obtain the system performance. Section 3 gives the design and implementation algorithm method for 1024-FFT where the Radix-4 and the proposed of parallel processing are detailed. Next, section 4 talks about the proposed three real complex multiplications. In section 5, the detail of 64-QAM demapping method is shown. Then, section 6 and 7 give the mmeasurement setup and experiment results, respectively. Finally, the conclusion is given in the last section.

2. HARDWARE CONSTRAINS

In this section, the summarized constrains for the entire implementation of the FFT computation algorithms will be given. For efficient realtime processing several constraints have to be covered to meet the performance requirements of algorithms as well as hardware. The bit resolution for all processing blocks is defined by 18 bit in signed fixed-point binary number system [9]. The first 8 bits is for the signed integer and the remaining of 10 bits is for the fractional. The designed target of the sampling clock for output stream is 400 Msps. However, the FPGA logic performance is limited to a few MHz clock cycles and decreases rapidly with the increased computation complexity. Therefore, data must be processed in parallel with the clock of around 50 - 150 MHz. In our design, the number of parallel processing channels are 16 inputs topology. Then, the internal FPGA processor clock results to 50 MHz. In addition, double data rate (DDR) clock type is used for high speed ADC.

3. 1024 FFT DESIGN AND IMPLEMENTATION ALGORITHM

For the FFT calculation, the size of 1024-point is designed and implemented in this work. Normally, the Radix-2 and Radix-4 are very efficient and well-known for FFT calculation algorithms. However, in this work, Radix-4 is used because its calculation time is shorter and it takes fewer resources than Radix-2. For example, the Radix-2 algorithm needs 10 stages for calculating a 1024-point FFT, whereas Radix-4 calculates the result in only 5 stages. Therefore, Radix-2 needs more complex multiplications in comparisons to Radix-4 which it is also calculated faster than Radix-2. Therefore, in this work, the algorithm is implemented as a Radix-4 butterfly structure, as shown in Fig. 2.

In Fig. 2, there are four input signals $x(n)$, $x(n+N/4)$, $x(n+N/2)$ and $x(n+3N/4)$, and four output signals which are multiplied with the twiddle factor (TW), denoted by W_N^{kn}. k is the subcarrier index. The structure of calculation is expressed by [10],

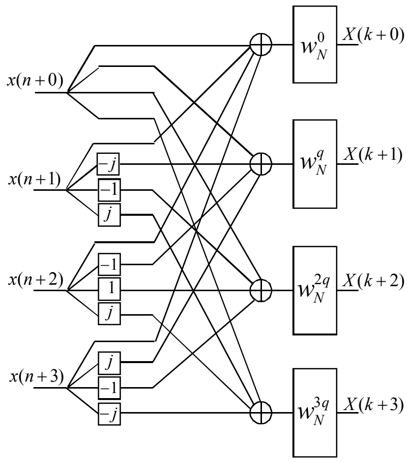


***Fig. 2** Equivalent butterfly structure of the Radix-4.*

$$X(4k+0)=\sum_{n=0}^{N/4-1}\begin{bmatrix} x(n)+x\left(n+\frac{N}{4}\right)+ \\ x\left(n+\frac{N}{2}\right)+x\left(n+\frac{3N}{4}\right)\end{bmatrix}W_N^0 W_{N/4}^{kn}, \quad (1)$$

$$X(4k+1)=\sum_{n=0}^{N/4-1}\begin{bmatrix} x(n)-jx\left(n+\frac{N}{4}\right)- \\ x\left(n+\frac{N}{2}\right)+jx\left(n+\frac{3N}{4}\right)\end{bmatrix}W_N^n W_{N/4}^{kn}, \quad (2)$$

$$X(4k+2)=\sum_{n=0}^{N/4-1}\begin{bmatrix} x(n)-x\left(n+\frac{N}{4}\right)+ \\ x\left(n+\frac{N}{2}\right)-x\left(n+\frac{3N}{4}\right)\end{bmatrix}W_N^{2n} W_{N/4}^{kn}, \quad (3)$$

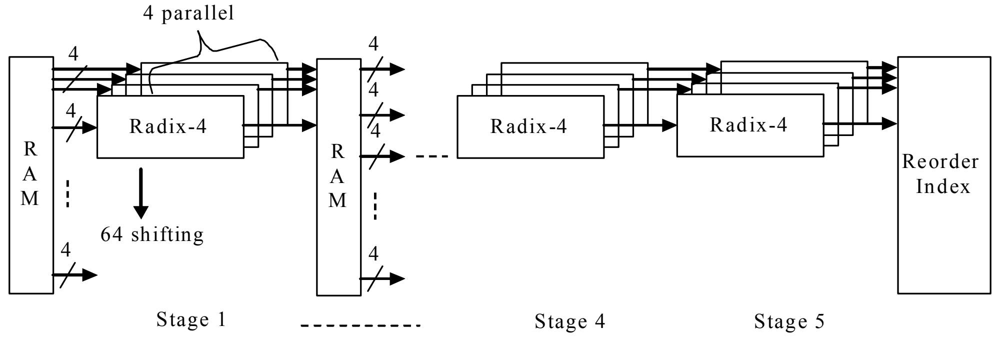


***Fig. 3** Parallel calculation topology details of the proposed 1024-point FFT computation.*

$$X(4k+3)=\sum_{n=0}^{N/4-1}\begin{bmatrix} x(n)+jx\left(n+\frac{N}{4}\right)- \\ x\left(n+\frac{N}{2}\right)-jx\left(n+\frac{3N}{4}\right)\end{bmatrix}W_N^{3n}W_{N/4}^{kn}. \quad (4)$$

where k and $n=0...N/4-1$. $W_N^0, W_N^n, W_N^{2n}, W_N^{3n}$ and $W_{N/4}^{kn}$ are TW. Additionally, this calculation is repeated $m=\log_4 N$ times for an N-point FFT. Finally, we can write a general FFT equation by,

$$X(k)=\sum_{n=0}^{N/4-1}\begin{bmatrix} x(n)+(-j)^k x\left(n+\frac{N}{4}\right)+ \\ (-1)^k x\left(n+\frac{N}{2}\right)+(j)^k x\left(n+\frac{3N}{4}\right)\end{bmatrix}W_N^{kn}. \quad (5)$$

Hence, the twiddle factor is given by

$$\begin{aligned} W_N^{kn} &= e^{\frac{2\pi kn}{N}} \\ &= \cos\left(2\pi\frac{kn}{N}\right)-j\sin\left(2\pi\frac{kn}{N}\right). \end{aligned} \quad (6)$$

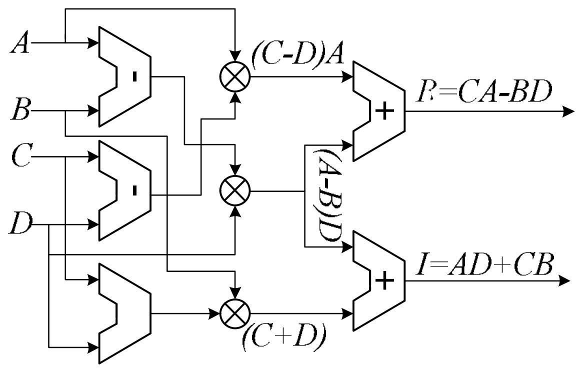


***Fig. 4** Complex multiplication with only 3 real multipliers.*

In our implementation, the algorithm is computed in 4-parallel Radix-4 sections for 16-parallel data streams. The input data of the 1st, 2nd, 3rd and 4th stage are selected according to indexes in equations (1)-(4). Therefore, after each stage the output data must be stored into RAM to select indexes for the next stage. The final process is to reorder the index of the data. In each stage of calculation, the twiddle factors are precalculated and stored into internal ROM with 18 bits by using Matlab. This setup allows data processing in realtime without any feedback loops, cf. Fig. 3. In addition, to complete 1024-point FFT calculation, there needs 64 (=1024/16) shifted input to each calculation stage.

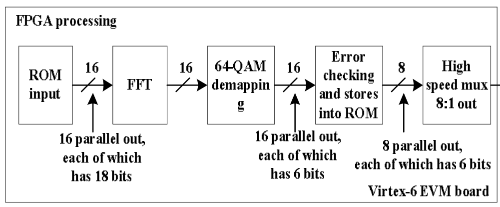


***Fig. 5** The measurement setup for realtime experimental of high speed FFT calculation.*

4. THREE REAL COMPLEX MULTIPLICATION

Due to the limitation of the FPGA DSP units for multiplication the following scheme to perform complex multiplications is considered. Assuming two complex values $X=A+jB$ and $Y=C+jD$, the regular approach for complex multiplication leads to for real multiplications and two additions which is expressed by [11],

$$\begin{aligned} Z &= XY \\ &= (CA-BD)+j(AD+CB). \end{aligned} \quad (7)$$

However, in this work, the complex number multiplication with only three real multipliers with five adders/subtractors is used, as detailed in Fig. 4.

Only *(C-D)A*, *(A-B)D* and *(C+D)B* are required multiplication. However, there is needed more adder and subtractor circuits.

5. 64-QAM DEMAPPING METHOD

The final module is demapping unit which is very simple block to implement. It is located before the error checking. From table. 1, we only take 8 most significant bits for comparing and making a decision of the constellation points. In this work, 64-QAM with Gray mapping is used. All the 64 points cannot be shown all in this paper. However, for example, 10 data demapping are shown in table 1. There are 8 MSB bits for both I and Q part which are used for demappingthe bit out streaming, the demapping out is shown in the last column in Table 1. For example, at the QAM point of 7+7i, its uses 00000111 for I and Q to be mapped to 111000.

QAM point	Bits I part in FPGA	Bits Q part in FPGA	Bit streaming of demapping out
7+7i	00000111	00000111	111000
-7-7i	11111001	11111001	000111
5+5i	00000101	00000101	110001
-5-5i	11111011	11111011	001110
-7+5i	11111001	00000101	000001
3+3i	00000011	00000011	101010
-3-3i	11111101	11111101	010101
1+1i	00000001	00000001	100011
-1-1i	11111111	11111111	011100
1+7i	00000001	00000111	100000

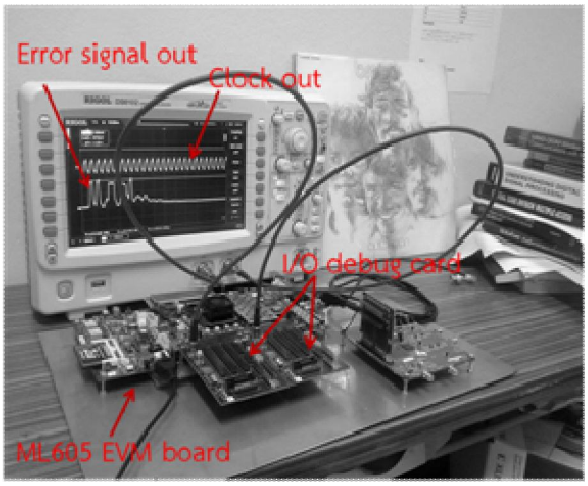


***Fig. 6** Bit error checking method for the proposed high speed 1024-*FFT calculation.

6. MEASUREMENT SETUP

In order to verify the implementation performance of the high speed FFT calculation, the experimental detail is shown in Fig. 5. The experimental setup is depicted in Fig. 6. The figure is included the Virtex-6 ML605 EVM board with installing I/O debug cards and the oscilloscope with 1 GHz bandwidth. The oscilloscope shows also the real-time measurement signal out which is contained of clock and error signal out.

The received four OFDM frames are pregenerated by using Matlab transmitter modeling including the limitation of ADCs resolution of 18 bits. All of them are done in off-line. The four time domain OFDM symbols with Gray 64-QAM mapping are generated by Matlab and it is stored in FPGA. The total useful 720 subcarriers out of 1024 subcarriers are used to transmit information data and the remaining is set to zero. The first and the last 5 subcarriers are also modulated by zeros, which is used for oversampling and avoid any others interferences. Please note that there are no pilot for others proposes. Therefore, 17,280 (=720×4×6) bits are transmitted in total (or 17,280 bits data are processed in side FPGA). The generated data is stored into an internal ROM and it works as an input data for FFT computation.

Next, the 16-parallel input slots, which are already saved inside the FPGA, are fed out to the next process. Then, the output from the FFT processing is fed into the 64-QAM demapping and followed by error checking process where it is realtime measured by oscilloscope.

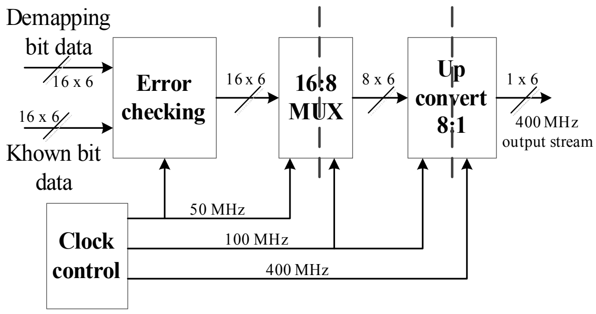
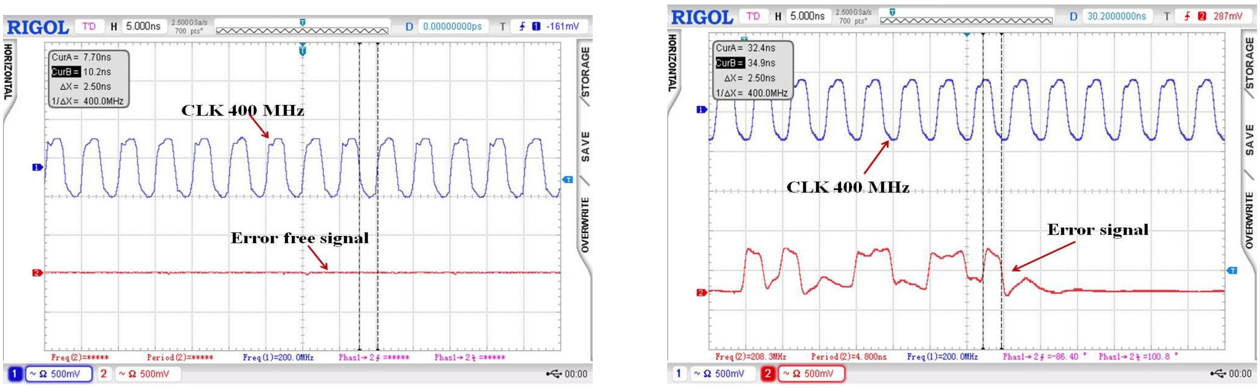


***Fig.** 7 Bit error checking method for the proposed high speed 1024-FFT calculation.*

For the error checking unit, the detailed is shown in Fig. 7. Firstly, the known data bit of 17,280 bits, which is demapped from 64-QAM, is pregenerated in Matlab and stores it into internal ROM. Next, the demapped bits signal from the FPGA processing are compared with the saved known data bits by using normal XOR gates, and it is done in 16-parallel topologies. The 16-parallel outputs from the XOR gate are fed into the high speed multiplex 16:8. Then, to feed the streaming bit output at 400 Msps, we need one more high speed multiplexing by using OSERDESE1 [12] from Xilinx primitives I/O. The last multiplex is fed out 8 to 1 data stream with 6 bits (=$\log_2(64)$) in parallel. Finally, output stream is fed into the debug card output pin where the realtime error measurement signal is shown on the oscilloscope. The result is shown in Fig.8. As can be seen that the internal clock is on 50MHz, which is very easy to work with. Especially, when the complexity of DSP algorithm is increased, the internal clock has to be in the range between 50MHz to 100MHz. Otherwise, timing inside the FPGA would be difficult.

7. EXPERIMENT RESULTS

In this section, the implementation result of 1024-point FFT computation with 64-QAM constellation mapping is verified in realtime measurement. The 64-QAM symbols are normalized by$1/\sqrt{2}$. In this test, assuming that the signal to noise ratio (SNR) is infinite and there is no communication impairments channel. Only the FFT computation and the 64-QAM demapping are considered. In addition, to make sure that the implementation is worked well and correct, the transmitted of 7 bits out of 17,280 bits are forced to be error at the transmitter. The measurement result of the error checking as discussed in last section is depicted in Fig 8.



(a) (b)

Fig. 8 *Real time measurement signal results: A. No force bit to be error and B. The seven bits are forced to be error.*

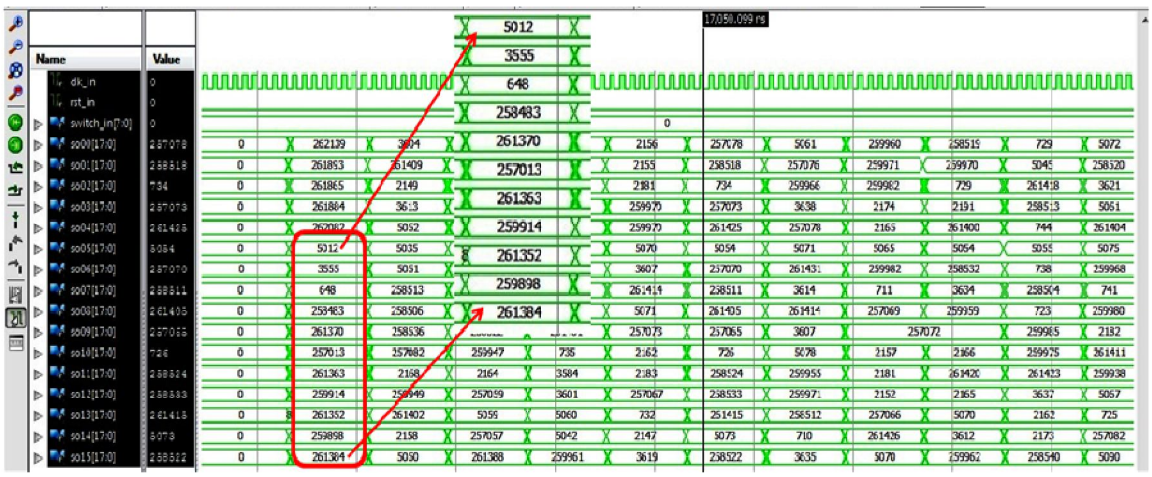


Fig. 9 *16-parallel output of FFT calculation in place and route simulation level by using Isim.*

Fig. 8A shows the error free signal which is all bits from the FPGA calculation and the precalculated by Matlabd are unforced to be error. Fig. 8B depicts 7 bits error signal, which we have forced them by the saved data, respectively. As can be seen, there are 7 bits errors as we expect. In addition, the data stream speed of 400 MHz is achieved. Therefore, the implementation can be worked well. However, in the figure, the clock speed is 200 MHz because the system is worked with double data rate (DDR) clock type.

Next, the 64-QAM symbol data of 16-parallel topologies are shown where the result is simulated in place and route level by using Isim from ISE version 13.4 [13]. After the power of the 64-QAM symbol is normalized, the magnitude of which is reduced to 4.95, 3.5, 3.1 and 0.7, for both I and Q components, respectively. In this work, the fix-point number system of word length of 18 bits is used, where the fractional part is 10 bits and the integer part is 8 bits. Therefore, the magnitude of 0.7 is represented by 717, -0.7 is 261427, 2.1 is 2150, -2.1 is 259994, 3.5 is 3584, -3.5 is 25856, 4.95 is 5096 and -4.9 is 257126 in unsigned decimal number system, respectively. From Fig. 9 and due to the I/O pins are limited; therefore, only the real part is shown for all 16-parallel outputs.

For example, let's observe the first 10 transmitted data of 64-QAM symbols which the true transmitted. It is precalculated in off-line, The 10 data consist of 4.9, 3.5, 0.7, -3.5, -0.7, -4.9, -0.7, -2.1, -0.7 and -2.1, respectively. As can be seen in the zoom out of the inset Fig. 9, the computation from the FPGA is well agreed with the transmitted signals which are pregenerated by Matlab in off-line. The FPGA processing output is represented by the unsigned decimal number system.

Finally, the resources usage of ML605 EVM board after implementing in the place and route level is reported and it is shown in table 2.

In Table.2, only the importance usage parameters are reported. The number of slice registers consumes 17%, LUT is 35% and Block RAM/FIFO is 35%, respectively. Especially, the DSP unit which is used for complex number multiplication consumes only 17% or

138 circuits out of 780 circuits. By this implementation, it is confirmed that there is a lot of the number slice and block RAM are free for others processing, such as channel estimate and equalization and OFDM frame synchrinization.

Table 2 *The number resources usage of ML605 EVM board.*

Device Utilization Summary			
Resource	Used	Available	Utilization
Number of Slice Registers	40,090	301,440	26%
Number used as Memory	14,377	58,400	24%
Number of occupied Slices	16,180	37,680	42%
Number of DSP48E1s	138	768	17%

8. CONCLUSIONS

FPGA calculation of high speed 1024-point FFT with 64-QAM constellation demapping has been presented. The calculation is based-on Radix-4 topology. To meet a huge of calculation throughput, parallel processing has been proposed where the 16-parallel input topologies for each processing stage is applied. The aimed clock speed for the output bit streaming or ADC update rate is 400 MHz. As a result, the bit rate of 2.4 Gbps is achieved. The realtime experimental results showed that the clock speed and data stream output are met the targets. The FPGA resource usage is moderate. From all the results, the design and implementation of 1024-point FFT has been proved that it is well suited for high speed multi-gigabit OFDM communication systems.

REFERENCES

[1] M. Engels, "Wireless OFDM Systems: How to make them work?," Springer US, 2002.

[2] K. Fazel and S. Kaiser, "Multi-carrier and spread spectrum systems: from OFDM and MC-CDMA to LTE and WiMAX," 2nd ed, John Wiley & Sons, 2008.

[3] C. Choi, E. Grass, M. Piz, M. Ehrig, M. Marinkovic, R. Kraemer, C. Scheytt, "60-Ghz OFDM Systems for Multi-Gigabit Wireless LAN Applications*," in Proc. IEEE Consumer Communications and Networking Conference (CCNC), pp.1-5, 9-12 Jan. 2010.*

[4] K. Sobaihi, A. Hammoudeh, D.Scammell, "FPGA Implementation of OFDM Transceiver for a 60 GHz Wireless Mobile Radio System*," in Proc. IEEE International Conference on Reconfigurable Computing and FPGAs (ReConFig) 2010, pp.185-189, 13-15 Dec. 2010.*

[5] C. Dick, F. Harris, "FPGA implementation of an OFDM PHY," in Proc. IEEE Conference Record of the Thirty-Seventh Asilomar Conference on Signals, Systems and Computers 2004, vol.1, pp.905-909, 9-12 Nov. 2003.

[6] J. Garcia, R. Cumplido, "On the design of an FPGA-based OFDM modulator for IEEE 802.16-2004*," in Proc. IEEE International Conference on Reconfigurable Computing and FPGAs 2005 (ReConFig 2005), 28-30 Sept. 2005.*

[7] A. Mecwan, D. Shah, "Implementation of OFDM transceiver on FPGA*," in Proc. International Conference on Engineering (NUiCONE), 2013 Nirma University, pp.1-5, 28-30 Nov. 2013.*

[8] Kidsanapong Puntsri, "FPGA Implementation of High Speed 1024-point FFT for Multi-gigabit Based band OFDM Communication Systems" *in Proc. The 38th Electrical Engineering Conference (EECON-38), Nov. 2015.*

[9] R. G. Lyons, "Understanding Digital Signal Processing," (3th Edition), Pearson Prentice Hall, 2011.

[10] J. G. Proakis, D. G. Manolakis, "Digital Signal Processing Principles, Algorithms, and Applications," (4th Edition), Pearson Prentice Hall, 2007.

[11] http://web.ece.ucdavis.edu/~bbaas/281/slides/Handout.complex.arith.pdf

[12] www.xilinx.com/support/documentation/user_guides/ug361.pdf

[13] http://www.xilinx.com/support/documentation/sw_manuals/xilinx11/ug682.pdf

Kidsanapong Puntsri received B.Eng. degree in telecommunication engineering from Mahanakorn University of Technology (MUT), Thailand, in 2002, and M.Eng. degree in telecommunication engineering from King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand, in 2005. In 2014, he was obtained his Dr.-Ing. degree in the area of optical communication systems from the University of Paderborn, Germany. At the present, he is a lecturer at department of electronics and telecommunications, Rajamamgala University of Technology Isan, Khon Kaen Campus, Thailand. His main research interests include multi-carrier communications in both optical and wireless systems and realization of communication systems by field-programmable gate array (FPGA). He has published more than 30 contribution papers in IEEE both conference and journal papers.

Fast Active Contour Model using Simulated Annealing with Edge Flow for Texture Segmentation

Tanunchai Boonnuk and **Sanun Srisuk**

Manuscript received November 2, 2015
Revised December 1, 2015

ABSTRACT

Texture images is difficult to define the object boundaries or to segment the image into sub-regions. This paper provides an effective method for texture segmentation using an active contour model with edge flow technique and simulated annealing. This technique utilizes the edge flow vector as the external force in an active contour model and optimized by using simulated annealing. In this study, we demonstrate the performance of our technique using samples from synthetic image. These images are transformed into gray-scale before processing the texture segmentation. The experimental results show that the proposed method provides more accurate segmentation results.

Keywords: *component; texture segmentation, active contour model, edge flow vector, simulated annealing.*

1. INTRODUCTION

In order to simplify digital images for further analysis, image segmentation is used to partition an image into multiple segments. Today, image segmentation is widely utilized in various applications, such as analyzing surface defects in cigarette packages [1], road-sign detection [2], and identifying objects such as tumors [3] and cancer [4] in medical images. Several techniques have been developed and utilized for image segmentation. Moreover, some techniques use color, gray-scale, or texture to divide the image, such as the so-called edge-flow technique [5].

Digital images that contain texture are very difficult to segment using the thresholding method or edge detection. The edge flow technique has been developed for textured boundary detection and utilizes an edge flow vector constructed from the direction of change in color and texture at each image location. The boundary can be detected at the location of the opposite vector flow [6].

The active contour model is an image-segmentation technique introduced by Kass et al. [7]. Later, this technique was developed into two models: edge-based active contour models and region-based active contour models. Edge-based active contour models use the edge as an external force to move the contour [8], whereas region-based active contour models use the region as an external force [9]. The edge of the image is considerably important for an edge-based active contour model because this type of model uses the edge of input images to calculate the main force for driving and shaping contour for the object in the image.

Simulated annealing is a probabilistic technique for approximating the global optimum of a given function. Specifically, it is a metaheuristic to approximate global optimization in a large search space. It is often used when the search space is discrete (e.g., all tours that visit a given set of cities). For problems where finding the precise global optimum is less important than finding an acceptable global optimum in a fixed amount of time, simulated annealing may be preferable to alternatives such as brute-force search or gradient descent [10].

In this paper, we provide an alternative method for texture segmentation using an active contour model with an edge flow vector and optimized by using simulated annealing technique. This technique utilizes an edge flow vector as the external force in an active contour model. Edge flow vectors are constructed from the direction of change in color and texture at each image location. The deformation of contour lines is based on energy minimization.

We demonstrate the effectiveness of our technique using samples from synthetic image. The details for the algorithm and experimental results are described in what follows.

2. METHODOLOGY

2.1 Edge flow technique

The edge flow method was introduced in 2000 by Ma and Majunath [6]. This technique offers a novel method for boundary detection that results in a higher image-segmentation quality, suitable for images that contain texture. First, the direction and position of the edge vector are defined near boundary of the object, as shown in Fig. 1.

Because image attributes such as color, texture, or their combination can be used to compute the edge energy and the direction of flow, this scheme provides a general framework for integrating different image features for boundary detection.

Tanunchai Boonnuk is with the Faculty of Science and Technology, Loei Rajabhat University, Loei, Thailand (email: boonnuk2002@hotmail.com)
Sanun Srisuk is with the Faculty of Industrial Technology, Nakhon Phanom University, Nakhon Phanom, Thailand (email: e-mail: srisuk.s@gmail.com)

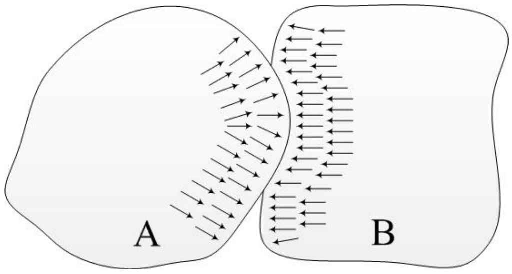


Fig. 1 *Edge flow direction.*

The edge-flow parameters consist of $E(s,\theta)$, $P(s,\theta)$, and $P(s,\theta+\pi)$, where $E(s,\theta)$ is used to measure the edge intensity of position s and direction θ, $P(s,\theta)$ is the probability of finding the edge at position s and direction θ, and $P(s,\theta+\pi)$ is the probability of finding the edge at position s and the opposite direction of θ (i.e., direction $\theta+\pi$).

The edge intensity (E) and probability (P) can be computed using image components such as color, surface, and gray-scale. Then, the edge-flow vector $\vec{F}_{(s)}$ is determined as a function of $E(s,\theta)$, $P(s,\theta)$, and $P(s,\theta+\pi)$, where the magnitude of $\vec{F}_{(s)}$ is the edge energy for the whole image, and the direction of $\vec{F}_{(s)}$ is oriented at the closest edge location. The distribution of $\vec{F}_{(s)}$ generates a flow field that spreads along the direction of the edge flow until it finds the opposite edge vector or the edge of the object. The intensity is defined as follows:

$$E(s,\theta) = \sum\nolimits_{a\in A} E_a(s,\theta).w(a) \tag{1}$$

where $\sum\nolimits_{a\in A} w(a) = 1$

$$P(s,\theta) = \sum_{a\in A} P_a(s,\theta).w(a) \tag{2}$$

where $E_a(s,\theta)$ and $P_a(s,\theta)$ respectively represent the energy and probability of the edge flow computed from image attribute a, $a\in\{intensity/color,texture,phase\}$, and $w(a)$ is the weighting coefficient associated with image attribute a.

The direction of the flow is estimated at each location s in the image as follows: $[E(s,\theta), P(s,\theta), P(s,\theta+\pi)]$, where $0\leq\theta\leq\pi$. We first identify a continuous range of flow directions that maximize the sum of probabilities in a corresponding half plane:

$$\Theta(s) = \arg\max_{\theta}\left\{ \sum_{\theta(s)\leq\theta'<\theta+\pi} P(s,\theta') \right\} \tag{3}$$

The edge flow vector is then defined to be the following vector sum:

$$\vec{F}_{(s)} = \sum_{\Theta_{(s)}\leq\theta<\Theta_{(s)}+\pi} E_{(s,\theta)}.\exp(j\theta) \tag{4}$$

where $\vec{F}_{(s)}$ is a complex number with its magnitude representing the resulting edge energy and its angle representing the flow direction.

2.2Traditional Active Contour Model

In 1987, Kass et al. introduced an active contour model for image segmentation [7]. Known as a "snake," this method requires the initial contour as a starting point. The shape of the contour is modified and moved toward the boundary of the objects in an image. Let $\mathbf{x}(s) = [x(s),y(s)]$ and $s\in[0,1]$ be the curve that moves toward the boundary of an object in an image. The aim with an active contour is to minimize its energy function, subject to constraints from a given image:

$$\begin{aligned} E_{snake} &= \int_0^1 \frac{1}{2}[\alpha|x'(s)|^2 + \beta|x''(s)|^2] \\ &+ E_{ext}(x(s))ds \end{aligned} \tag{5}$$

where α and β are weighting parameters that control contour smoothing while the contour is moving, x' and x'' are first- and second-order derivative of the contour, respectively, and E_{ext} is external energy obtained from image features such as the edge and texture boundary.

The external energy E_{ext} is defined such that it moves the contour close to the image features:

$$E_{ext}(x,y) = -\|\nabla[G_\sigma(x,y) * I(x,y)]\|_2 \tag{6}$$

where $G_\sigma(x,y)$ is a two-dimensional Gaussian function with standard deviation (σ). For instance, when the image is a black line on a white background, a suitable external energy is

$$E_{ext}(x,y) = G_\sigma(x,y) * I(x,y) \tag{7}$$

To increase the range for capturing an active contour, a large σ is often necessary. The "snake" that minimizes energy typically obeys the Euler equation:

$$\alpha|x''(s) - \beta|x''''(s) - \nabla E_{ext} = 0 \tag{8}$$

The energy function can be understood as a force-balance equation:

$$F_{\text{int}} + F_{ext} = 0 \tag{9}$$

where $F_{\text{int}} = \alpha|x''(s) - \beta|x''''(s)$, and $F_{ext} = -\nabla E_{ext}$.

The internal force F_{int} is used to control the stretching and bending of the contour, whereas the external force F_{ext} influences the contour toward the image features—i.e., usually the edges.

To solve Eq. (8), the edge flow (EF) snake is designed to be dynamic, defining x as a function of time. The dynamic snake equation is as follows:

$$X_t(s,t) = \alpha x''(s,t) - \beta x''''(s,t) + \mathrm{v} \tag{10}$$

where v is the external force

2.3 Simulate annealing

Simulated annealing (SA) is a probabilistic technique for approximating the global optimum of a given function. Specifically, it is a metaheuristic to approximate global optimization in a large search space. It is often used when the search space is discrete (e.g., all tours that visit a given set of cities). For problems where finding the precise global optimum is less important than finding an acceptable global optimum in a fixed amount of time, simulated annealing may be preferable to alternatives such as brute-force search or gradient descent.

2.4 Ours Algorithm

The algorithm of texture segmentation using active contour model incorporated with edge flow are described as follows.

Step1: Initialization
Step2: Computing Vector flow field
Step3: Computing Magnitude of Flow Field Vector ($\| \vec{F}_{(s)} \|$)
Step4: Computing F_{int}
Step5: Computing F_{ext}, $F_{ext} = \| \vec{F}_{(s)} \|$
Step6: Checking magnitude
  If (magnitude is high) then
    α=1
  Else If (magnitude is middle) then
    α=0.5
  Else α=0.1
  End if
Step7: Adjusting active contour to close to the direction of edge image
Step8: Finding E_{snake}
Step9: End if E_{snake} is a lowest value
  or goto 4 if not

3. RESULTS

We demonstrated the usefulness of our new approach for texture segmentation. Our study used synthetic images. We compared active contour model using edge flow vector with and without simulated annealing. The images were transformed into gray-scale before processing the texture segmentation. With textured images, the edge flow energy is high along the boundary between two textured regions. This can be used to terminate the active contour where the energy is minimized (-($V(x,y)+H(x,y)$)). The experimental result are provided in the following:

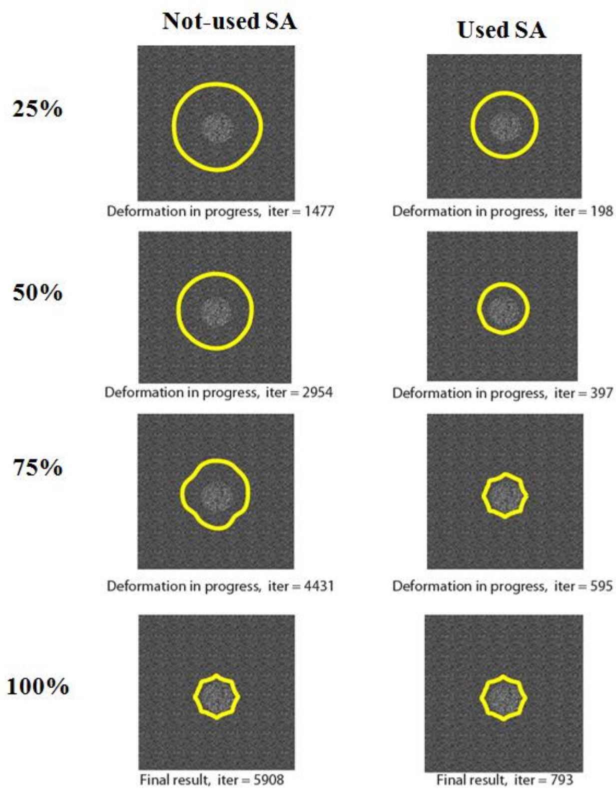


***Fig.** 2 Experimental result.*

4. DISSCUSTION

In our experiment, we found that textured images after segmentation using active contour model using edge flow vector with and without simulated annealing. It found that active contour model with edge flow vector using simulated annealing has result better than active contour model with edge flow vector not using simulated annealing (number of iteration was lower) . However, our proposed technique uses an edge flow vector as the contour guide in the active contour model. The edge flow vector identifies the flow direction of each pixel near the boundary. Moreover, with our technique, the tracery is understood as distinct from the edge of the object. As a result, the active contour model with an edge flow vector could be optimized by simulated annealing.

5. CONCLUSSION

This paper provided an effective method for texture segmentation using an active contour model with edge flow technique and simulated annealing. This technique utilized the edge flow vector as the external force in an active contour model and optimized by using simulated annealing. In this study, we demonstrate the performance of our technique using samples from synthetic image. It found that active contour model with edge flow vector using simulated annealing has result better than active contour model with edge flow vector not using simulated annealing.

REFERENCES

[1] Y. Qu, B. He, and G. Liu, "The Application of Image Processing Techniques in Analysis of Cigarette Packets Surface Defects," in International Conference on Computer, Communications and Information Technology (CCIT), Beijing, 2014. pp. 313-316

[2] F. Khan, S. M. A. Bhuiyan and R. R. Adhami, "Image segmentation and shape analysis for road-sign detection," IEEE Transactions on Intelligent Transportation Systems, vol. 12, 2011, 83-96.

[3[T. Logeswari and M. Karnan, "An improved implementation of brain tumor detection using soft computing," in International Conference on Communication Software and Networks, Singapore, 2010, pp. 147-151.

[4] Y. Xu, J. Y. Zhu, I. Eric, C. Chang, M. Lai, and Z. Tu, " Weakly supervised histopathology cancer image segmentation and classification," Medical image analysis, vol. 18, 2014, pp. 591-604.

[5] S. Srisuk, "Image segmentation," in Advanced Image Processing, Mahanakorn University of Technology, Bangkok, 2013, pp 139-188. (in Thai)

[6] W. Y. Ma and B. S. Manjunath, "EdgeFlow: A technique for boundary detection and image segmentation," IEEE Transactions on Image Processing, vol. 9, 2000, pp. 1375-1388.

[7] M. Kass, A. Witkin, and D. Terzopoulos, "Snakes: Active contour models," International Journal of Computer Vision vol. 1, 1988, pp. 321-331.

[8] C. Xu and J. L. Prince, "Snakes, shapes, and gradient vector flow," IEEE Transactions on Image Processing, vol. 7, 1998, pp. 359-369.

[9] T. F. Chan and A. L. Vese, "Active contours without edges," IEEE Transactions on Image Processing, vol. 10, 2001, pp.266-277.

Tanunchai Boonnuk M.Sc. is a lecturer at the faculty of Science and Technology, Loei Rajabhat University, Loei, Thailand. His current research interests are medical image processing.
Email: boonnuk2002@hotmail.com

Sanun Srisuk, D.Eng., is an associate professor at the faculty of Industrial Technology, Nakhon Phanom University, Thailand. His research interests are computer vision and image processing especially on face recognition, iris recognition, texture analysis, and video analytics.

A Review of Parallel-Processing Approaches for Solving Engineering Problems: Definitions and Applications

Nuapett Sarasiri

Manuscript received November 17, 2015
Revised December 12, 2015

ABSTRACT

Parallel-processing approach has been involved in various applications since this has the potential of providing speedup computing. Descriptions of different terms related to parallelization, such as parallel processing or parallel computing, parallel programing, parallel metaheuristics and parallel computing in MATLAB are presented. In this article, the parallel computing in MATLAB is pointed out because this is the main tool for many applications in engineering areas. Thus, the main functions employed by Parallel Computing Toolbox^{TM} are exhibited with some simple examples. Some applications in engineering that utilize parallel-processing approach are also reviewed.

Keywords: *Problems solving, Parallel-Processing.*

1. INTRODUCTION

As the size of simulation problems in engineering and science areas becomes larger, computing tasks demand a large amount of resources, and consume a long time to be solved. Parallel computation is one of effective techniques to address these difficulties. The term *parallel* used in this article refers to "simultaneous or concurrent execution of individual tasks being carried out at the same time" [1].This parallel or distributed computing can take advantage of multicore and multiprocessor computers in order to use their full computational power and therefore, reducing computation time. Recently, new developments in parallel technologies, both hardware and software have been developed. Meanwhile, personal computers today have multiple cores that enable multiple threads to be executed simultaneously.

Today, microprocessors and the parallel machine technologies are dominated by reduced instruction set computer and processors [2]. The processors have been produced with several power efficient computing units on one chip, which have been independently controlled and can be accessed in the same memory. In this regard, multicore processors are used for single computing units and the entire processor contains several cores. Thus, it can be noticed that the use of multicore processors makes computer machines small parallel systems. For instances, dual- core and quad-core processors have been developed since 2009 as a standard for normal desktop computers and a year later, the chip manufacturers introduced oct-core processors. It can be considered that the number of cores per processors chip will be increased every 18-24 months according to prediction of Moore's law. Currently, the cores are available for application programs providing a potential high performance. In 2015, Intel Processor Company has reported that a typical processor chip consists of dozens up to hundreds of cores [3]. The execution time is significant when performed in parallel computing as it consists of the time for the computation on processors or core and the time for data exchange or synchronization. One potential benefit of parallel computing is based on the relative saving in execution time as in terms of speedup, which can be expressed in equation (1) and (2).

$$S_p(n) = \frac{T^*(n)}{T_p(n)} \tag{1}$$

where, n is the number of processors, $T^*(n)$ is the execution time of the sequential implementation, $n=1$, and $T_p(n)$ is the execution time of the parallel implementation with n processors. In an idea situation, the communication time between processor and memory is neglected, we can obtain, $T_p(n) = T^*(n)/n$, and the above equation provide

$$S_p(n) = n \tag{2}$$

It is rare indeed to get this linear increase in computation domain due to several factors.

There are various applications, which utilize the parallel computing, for instance, simulations of weather forecast using complex mathematical models, computer graphics applications for film and advertising industry, rush hour traffic, automobile assembly line. In addition, parallel computing has been applied to numerical simulations of complex systems and grand challenge problems such as chemical and nuclear reactions, biological, human genome, geological, seismic activity, mechanical devices, electronic circuits and manufacturing processes. Moreover, some applications require the processing of large amounts of data for example parallel databases, data mining, oil exploration,

Nuapett Sarasiri is with the Department of Electrical Power Engineering, Faculty of Engineering, Mahanakorn University of Technology, Thailand (email: n.sarasiri@hotmail.com)

web search engines, web based business services, and collaborative work environments, among others.

This article is organized as follows: Section 2 presents a brief overview of parallelization, including parallel processing (computing), parallel programing along with parallel metaheuristics. Subsequently, parallel computing in MATLAB and its more relevant functions as well as some examples are presented in Section 3. Section 4 gives reviews of parallel applications in engineering problems, and, finally, Section 5 presents the conclusions.

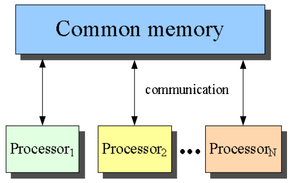
2. DEFINITIONS OF PARALLELIZATION

Parallelization in the level of parallel computing machines can be roughly classified according to the hardware supported parallelism, i.e. multicore and multiprocessor computers having multiple processing elements within a single machine, and cluster and grid computers using multiple computers. This article explains various meaning of parallelization. Definitions of parallel processing or parallel computing, parallel programing, parallel metaheuristics and parallel computing in MATLAB are described.

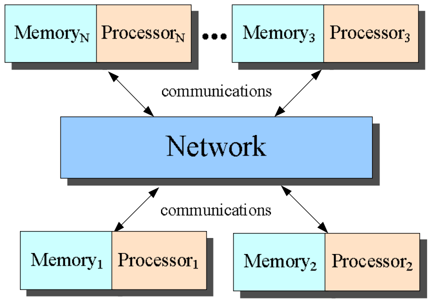
2.1 Parallel Processing or Parallel Computing

Large-scale simulation and data processing task such as mathematical modeling and algorithm development, can take an unreasonably long time to be completed or require a lot of computer memory. Such applications involve processing a huge amount of data or performing a large number of iterations [4]. Parallel computing is one of approaches to make the computation feasible by using multiple central processing units (CPUs) at the same time to solve each single problem. While the most modern computers currently possess more than one CPU, several computers can be combined together in a cluster manner; therefore, these multicore processors allow many computations to be completed in reasonable time or more quickly. Generally, parallel computing or parallel processing is a form of computation in which many calculations are carried out simultaneously [5]. A large task can be divided into smaller ones, which are solved in parallel to complete the job in less time than a single machine can do. Each processor works on its section of problem. Furthermore, processors can exchange information among each other within a set of memories based-on distributed computing.

An important classification of parallel computing is based-on the degree of sharing access to memory. A shared-memory of parallel computing can be classified in two structures, namely, multiprocessor desktop and multiprocessor computer clusters. Multiprocessor desktop is characterized by a structure model of shared-memory, shown in Fig.1(a), in which each processor can address locations in a common memory block. Processors in a shared-memory level can communicate with another one via the common memory with a suitable protocol. On the other hand, multiprocessor computer clusters are characterized by a structure mode of distributed-memory in Fig.1(b), in which processors can communicate with other processors by sending messages over a network [6-7]. Either structure can be chosen according to the application.



(a)



(b)

Fig. 1 *Structure models of parallel computing level: (a) a shared-memory and (b) a distributed-memory.*

2.2 Parallel Programming

Parallel programming is a computer programming technique that provides execution of instructions in parallel manner on either single computer or a cluster of computers [8]. In this, several programs can be performed simultaneously as multitasking on one machine employed by multiprocessor desktop or on several machines based-on multiprocessor computer clusters, in which the computing process uses computer resources such as memory blocks and registers. The predominant approaches in the parallel programming are open multiprocessing (OpenMP) for shared memory, and message passing interface (MPI) for distributed memory. The OpenMP is a shared memory application programming interface (API) that supports multiplatform shared memory and multiprocessing programming in C, C++ and Fortran. The MPI is a parallel programming model as a library, where communication between processes is done by interchanging messages over a distributed memory system. This approach can be written in different computer programming languages such as Fortran, C, C++ and Java. These techniques can process both Single Program Multiple Data (SPMD) and Multiple Program Multiple Data (MPMD) programing schemes. Nevertheless, application problems can be run on a computer cluster using both OpenMP and MPI as a hybrid model of parallel programming [8].

The primary goal of most parallel programming is to increase performance and scalability of a CPU instead of using high-cost machines such as mainframe and super computers. This also supports parallel software productivity, which has been becoming increasingly important in recent decades. Due to parallel hardware is becoming a low-cost commodity, it is now the time to seize this opportunity to develop efficient parallel programing [9].

2.3 Parallel Metaheuristics

Real-world optimization problems are always complex. Metaheuristics, which can provide global solutions within a reasonable time, are efficient solvers for this type of problems. Since standard metaheuristics are sequential in execution, solving large-scale real-world problems still demands very long time to complete the computing process. Parallel metaheuristic is a new advanced technique that has an ability to reduce both the numerical effort and the run time of a metaheuristic. This parallelization approach offers simultaneous runs of relevant programs to achieve the required solutions at high quality. The classification of this parallelization strategy applied to metaheuristics is defined according to the source of parallelism as follows [10]:

- Operation parallelization: This source of parallelism is usually applied within an iteration of the metaheuristic method. The limited functional or data parallelism due to large-scale values can be evaluated in parallel manner. The significant goal of this class of parallelism is to reduce the overall execution time by accelerating a repeated phase of the sequential algorithm, and to achieve higher quality solutions.
- Explicit space decomposition: This approach contains parallelization strategies, which decompose an entire search space into several or many sub-spaces. The sub-spaces can be searched by different search process in parallel manner. Usually, same metaheuristics are employed by different processes, but using different metaheuristics is not prohibited. This last option may require complicated analysis, software implementation and data management. This class of parallelism aims to avoid repetitive search in the parallel implementation, and to diversify the search to different regions within the search space.
- Multi-search threads: This class of parallelization is obtained from multiple concurrent explorations of the search space. Each concurrent thread may execute same or different metaheuristic methods. They may start from same or different initial solutions, and communicate during or at the end of the search to identify the best overall solution. This class of parallel strategies aims to improve the final solution by exploring different parts of the search space, and to increase the search speed.

3. PARALLEL COMPUTING IN MATLAB TOOLBOX

Nowadays MATLAB supports computational parallel processing through the MATLAB toolbox known as Parallel Computing Toolbox. Endowed with the latest *computer technology has* multiple processors or cores and hierarchical memory structures to against complicated worked. So far, the complicated engineering problems that consume long time to compute are considered to be solved by *Parallel Computing Toolbox*™ and *Distributed Computing Server*™ of MATLAB and Simulink. MATLAB and Simulink support parallel computing to run from one MATLAB session (client) to other MATLAB sessions (workers) on multiprocessor desktop and computer clusters. Parallel computing software is very useful for solving computationally intensive problems, and accelerating the processing of repetitive computations with large amounts of data by taking the full computational power of computing resources. MATLAB provides three kinds of parallelism, namely multithreaded, distributed computing, and explicit parallelism as follows [11]:

- Multithreaded parallelism: The functions automatically execute on multiple computational threads in a single MATLAB session on a multicore-enabled computer by sharing memory.
- Distributed computing**:** Multiple instances of MATLAB run multiple independent computations on separate computers with their own memories.
- Explicit parallelism: Several instances of MATLAB run on several processors or computers with separate memory blocks, and simultaneously execute a MATLAB command or m-function.

Parallel Computing Toolbox software helps to improve the performance of loop executions of iterative algorithms by letting several MATLAB workers to simultaneously execute individual loop iterations. For instances, a loop of 100 iterations runs concurrently on a computer cluster of 20 MATLAB workers. This means that each worker executes only five iterations of the loop. This may not be 20 times improvement in speed because of communication-time consuming, but the speed-up can be significant. It can be noticed that whether or not the loops take a long time for execution, the loop speed can be improved by distributing iterations to MATLAB workers. Providing, the loop iterations which run on the same computer using a multicore or multiprocessor, the speed can be improved even more through local workers. Parallel Computing Toolbox allows distributing a very large array to multiple MATLAB workers. Each worker performs only on its designated part of the array, while workers automatically transfer data among themselves, if necessary. Obviously, if the size of an array is not too large to fit in a local memory block, computing in a single MATLAB session is adequate.

In this article, we focus on some explicit parallel programing paradigms, such as parallel *for*-loop (*parfor*), single program multiple data (SPMD) block and distributed arrays. The detailed descriptions of these paradigms are given in the next sub-sections.

3.1 Parallel *for*-loop

A modification of a simple *for*-loop in parallel MATLAB is called parallel *for*-loop or *parfor-loop* conditional command. The basic concept of a *parfor-loop* is similar to the standard *for*-loop. Instead of executing a series of statement over a range of values, the *parfor-loop* is executed on MATLAB client and workers in parallel. To run the parallel loop, the MATLAB pool has to be created by using *matlabpool open* command in order to reserve a collection of MATLAB worker sessions on available cores of the machine, as the structure depicted in Fig. 2. The MATLAB pool consists of MATLAB sessions running on some local machines or an available cluster.

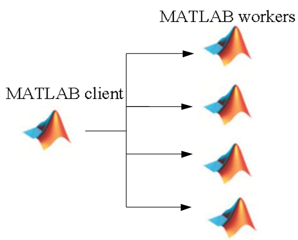


Fig.2 *MATLAB pool structure.*

Each worker evaluates iterations in no particular order and independent of each other. Therefore, each iteration is completely independent with non-sequence operation. During the operation of *parfor*, necessary data is sent from the client to the workers, and results are returned to the client and gathered together. After the process is completed, the array data of all elements is available in the MATLAB client; the MATLAB pool is closed by using *matlabpool close* command, and followed by releasing all workers. In addition, the *parfor*-loop command allows running parallel Simulink. The multiple models are simulated at the same time on different workers within the *parfor*-loop by using *sim* command, which helps to perform multiple simulation runs of the same model.

3.2 Single Program Multiple Data (SPMD) Block

The Parallel Computing Toolbox offers the SPMD construction to achieve a domain decomposition. In SPMD block, each processor concurrently runs the job. Fig.3 shows a short code list for an SPMD block in MATLAB environment. Coding is noticeably straightforward.

```
1. matlabpool open
2. spmd
       For each worker do statements
       in this SPMD block.
3. end
4. matlabpool close
```

Fig.3 *Code list for an SPMD block.*

Matlabpool is used to request parallel resources called workers by Parallel Computing Toolbox. It can be said that cores and processors behave as workers in MATLAB. Each worker has a unique identity called *labindex* to customize the execution of parallel jobs. When parallel resources are accessed, parallel jobs are created in an SPMD block, and then *Matlabpool* is closed to release parallel resources at the end of the parallel jobs.

3.3 Distributed Array

When complexity of a problem increases, the demanded computing resource may be extensive. Under this situation, computing may take many hours or days to be completed. Distributing these computational loads over processors can effectively shorten run-time. MATLAB provides an effective mean to distribute such loads via "distributed and codistributed arrays". In this, a distributed array means an array with its data being distributed from client workspace, and a codistributed one means an array with its data being codistributed within *spmd* statement created in local workers. These data can be stored in the workers of an open parallel pool. The *distributed* and *codistributed* commands are used to access elements of such arrays distributed in MATLAB client's workspace, and those of the arrays distributed among workers in parallel within an *spmd* environment, respectively. For example, consider a simple 4-by-8 matrix with ascending element values from 1 to 32, which is created in a client workspace, and then it becomes a distributed array as follows:

```
matlabpool open // create MATLAB pool.
     x = reshape(1:32, 4,8);
               // create an array on MATLAB client.
     y = distributed(x);
               // distribute an array to MATLAB workers.
  spmd
  disp(getLocalPart(y))
               // perform on workers in parallel.
               // y is codistributed array.
  end
matlabpool close   // close MATLAB pool
```

Fig.4 *Instruction for a distributed array.*

According to the code list in Fig.4, the command x = reshape(1:32, 4,8) creates an array, which has its elements of reshapes among 1 to 32 into a 4-by-8 matrix. The command y = *distributed*(x) partitions the original array into 4 since our platform is a quad-core. Then, it distributes these partitioned arrays to MATLAB client workspace. Fig.5 shows the original array with its associated sub-arrays. These sub-arrays are stored in parts on the workers of the open parallel pool. Inside the body of an *spmd* statement, each MATLAB worker has a unique value of *labindex* to execute the block in parallel.To display the actual data in local segments of the array from the body of an*spmd* statement, *getLocalPart*(y) returns the local portion of a codistributed array. Then, the parallel pool is closed by using *matlabpool close* command.

According to Fig.5, the full array in the client workspace is equally distributed into each worker as an array segment. Worker 1 stores columns 1 and 2 with an array segment from 1 to 8; worker 2 stores columns 3 and 4 including an array segment from 9 to 16, and so on.

worker 1		worker 2		worker 3		worker 4	
1	5	9	13	17	21	25	29
2	6	10	14	18	22	26	30
3	7	11	15	19	23	27	31
4	8	12	16	20	24	28	32

Fig.5 A result obtained from distributed array.

Considering, the codistributed array, a large array structure replicated on all workers can be partitioned into segments, and distributed across the workers. Each segment stores in the workspace of a different worker, which has its own array segment to perform. This aims to reduce the size of array from the client workspace, when the memory to store an initial replicated array is sufficient, and to provide faster processing, especially for large data sets. The codistributed array is normally used in the parallel environment within *spmd* statement. For example, A is a 3-by-10 matrix with ascending element values from 11 to 40, and the *codistributed* array is created inside *spmd* statement running in parallel as shown in Fig.6.

```
matlabpool open // create MATLAB pool.
Spmd
  A = [11:20; 21:30; 31:40]; // replicate array on each worker.
  D = codistributed(A)      // distribute array to MATLAB
                               workers.
  getLocalPart(D)         // each worker operates on its data.
end
matlabpool close          // close MATLAB pool.
```

Fig.6 *Instruction for a codistributed array.*

As an example in Fig.6, a 3-by-10 matrix is replicated on each worker in its own workspace under an spmd statement, and assigned to the variable A. D = *codstributed*(A) distributes a replicated array A using the default *codstributed* command inside an *spmd* statement. Noticeably, arrays A and D have the same size (3-by-10), and the array A exists in its full size on each worker, while only a segment of array D exists on each worker. When an array distributes to a number of workers, the MATLAB partitions the array A into segments and assigns one segment of the array to each worker as evenly as possible. The *getLocalPart* function returns the local portion of a codistributed array. At the end of code list, the parallel pool is released all of workers by using *matlabpool closed* command. The result of distributed array D is also 3-by-10 in size, but only a segment of the full array resides on each worker as shown inFig.7.

worker 1			worker 2			worker 3		worker 4	
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40

Fig.7*A result obtained from codistributed array.*

According to Fig.7, the full size on each worker is uniformly assigned into segments on each worker through the *codistributed* command. Worker 1 stores columns 1, 2 and 3, worker 2 contains column 4, 5 and 6, and so on.

Moreover, the explicit indexing of the distributed dimension for the codistributed array also includes using a *for*-loop over a distributed range (*for-drange*). The *for-drange* structure requires loop iterations to perform independently of each other, which each worker can be executed on the portion of range of it owns. It means that *in* a *for-drange* loop can access only the portion of a distributed array located to each worker. To illustrate this characteristic, Fig.8 shows an example code of using a *for-drange* loop.

```
matlabpool open      // create MATLAB pool.
    n = 1000;
    y = zeros(1, n, codistributor());
            // create a codistributed array.
  for x = drange (1:n)
            // use a for-loop over a distributed range.
    y(x) = x^2;
            // calculation performed on workers.
  end
    y = gather(y,1);
            // collect distributed arrays into worker 1.
matlabpool close  // close MATLAB pool.
```

Fig. 8 *An example code for the use of a for-drange loop.*

According to the code list in Fig.8, the loop increases from 1 to n. The loop x is partitioned by codistributed command into segments. Each segment becomes an iteration for a conventional for-loop on an individual worker. Thus, the calculation of y is performed on workers. After getting the computational results, an array data from each worker is collected into worker 1 using gather command.

4. REVIEW OF PARALLELIZATION IN ENGINEERING PROBLEMS

Some applications of parallel-processing approach in engineering problems are reviewed as follows:

Image processing [12]: This research presented a cluster of cameras to detect the position of objects in front of a wall-sized, high-resolution and tiled display. The experimental study uses 16 cameras, which connected pairwise to 8 computers in the first layer. Each computer processes images from two cameras, locating objects and determining their one dimensional position. The second layer can determine the object's 2D position using triangulation and the third layer distributes position data between the other three layers. The fourth layer is comprised of applications using the position data for interaction. The experimental study has shown that the parallel computer processing was satisfied with the results. The system achieves acceptable latency for applications such as 3D games.

Applying parallel computing in MATLAB and graphic processing unit (GPU) technology for image recognition [13]: In this research has carried out some of the key features of MATLAB parallel applications using GPU processors for image processing. This problem contains complicated matrix operations, thus, the parallel computing is significant in this area. The parallel computations on MATLAB and CUDA language (CUDA is a parallel library that uses an nVidia board) had been used on each level of image processing. For example, the first stage of vision system proposed to be the image acquisition stage supported by Image Acquisition Toolbox™ of MATLAB. Parallel convolution algorithm implemented in MATLAB using CUDA also used to compute the scalar output product. As the results show that the implementation in MATLAB provides four times faster, when compared to the sequential one. Thus, in this research can be summarized that it is possible to achieve speedup by using parallel computing written in CUDA running on the GPU calculated in MATLAB.

Geotechnical engineering [14]: This research used OpenMP-based approach to parallelize a geothermal simulation, which solved the coupled transient equations for ground water flow and heat transport. The overall parallelization strategy consists of an assembly and solution of two coupled systems of linear equations. This case study focuses on conductive model of a synthetic sedimentary basin consisting of 13 zones with different rock properties. The proposed techniques compared the performance of the OpenMP-parallelised code on four multicore platforms, which each machine has a certain number of processors and a specific number of cores on each processor. The results show that the speedup can be increased by increasing the number of processors.

Parallel optimization for solving flow shop problem [15]: This article presented a parallel tabu search algorithm for the permutation flow shop sequencing problem with the objective of minimizing the flow time. The performance of the proposed algorithm was comparable with the random heuristic technique. From the results, the speedup property of implementation was improved, when the number of processors increased.

5. CONCLUSIONS

This article has reviewed the different terms related to parallelization, such as parallel processing or parallel computing, parallel programing, parallel metaheuristics and parallel computing in MATLAB as well as the detailed descriptions have been given. According to the parallel computing in MATLAB is the main software for engineering applications, thus, its significant functions employed by Parallel Computing Toolbox™ have been presented along with some simple examples. The parallel processing in some engineering problems have been detailed.

REFERENCES

[1] Bentley J. E. "SAS Multi-Process Connect: What, When, Where, How, and Why". *Conference Proceedings in SUGI26*, Cary, NC: SAS Institute Inc., 2000.

[2] Tokhi M.O., Hossain M.A. and Shaheed M.H. "Parallel Computing for Real-time Signal Processing and Control". *Springer*, 2003.

[3] Rauber T. and Runger G. *Parallel Programming for Multicore and Cluster Systems*. Springer-Verlag Berlin Heidelberg, 2010.

[4] Roosta S.H., "Parallel Processing and Parallel Algorithms: Theory and Computation". *Springer-Verlag*, New York, Berlin Heidelberg, 1999.

[5] Almasi G. S. and Gottlieb A., *Highly Parallel Computing*. 2nd ed., Redwood City, Calif., Benjamin/Cummings Pub. Co., 1994.

[6] Eddy W. M. and Allman M., "Advantages of Parallel Processing and the Effects of Communications Time". *Research Report-NASA Glenn Research Center Report*, Number CR-209455, Ohio Univ.; Athens, OH United States. pp. 1-10, 2000.

[7] Gebali F., *Algorithms and Parallel Computing*. Published by John Wiley & Sons, Inc. Hoboken, New Jersey and Canada, 2011.

[8] Diaz J., Munoz-Caro C. and Nino A. "A Survey of Parallel Programming Models and Tools in the Multi and Many-Core Era". *IEEE Transactions on Parallel and Distributed Systems*. 23(8). pp. 1369-1386, 2012.

[9] Mc Kenney P.E. "Is Parallel Programming Hard, And, If So, What Can You Do About It?". *Linux Technology Center IBM Beaverton*, 2014.

[10] Alba E., *Parallel Metaheuristics: A New Class of Algorithms*. Published by John Wiley & Sons, Inc., Hoboken, New Jersey, 2005.

[11] MathWorks. *Parallel Computing Toolbox™ User's Guide*, version 4, MathWorks Inc., Natick, MA., 2008.

[12] Stodle D., Ha P.H., Bjorndalen J.M., and Anshus O. J. "Lessons Learned Using a Camera Cluster to Detect and Locate Objects". *Parallel Computing: Architectures, Algorithms and Applications*, C. Bischof et al. (Eds.), The authors and IOS Press., 2008.

[13] Szymczyk M Szymczyk P., "MATLAB and Parallel Computing". *International Journal on Image Processing & Communication*, vol. 17, no. 4, pp. 207-216, 2014.

[14] Wolf A., Rath V., and Bucker H. M. "Parallelisation of a Geothermal Simulation Package:A Case Study on Four Multicore Architectures", *Parallel Computing: Architectures, Algorithms and Applications*, C. Bischof et al. (Eds.), The authors and IOS Press., 2008.

[15] Bozejko W., and Wodecki M., "Solving the Flow Shop Problem by Parallel Tabu Search". *IEEE Proceedings on Parallel Computing in Electrical Engineering*, pp. 189-194, 2002.

Nuapett Sarasiri was born in Chachoengsao, Thailand, in 1984. She received her BEng (EE), MEng (EE) and Ph.D (EE) from Suranaree University of Technology (SUT), Thailand, in 2007, 2009 and 2014, respectively. She is currently a lecturer in the department of electrical power engineering at Mahanakorn University of Technology (MUT), Thailand. Her research interests include power systems, power electronics, power simulations, control systems, identifications, optimization search algorithms and parallel computing.

Factors Driving Thailand's Digital Economy

Naphawan Meesri and **Arnon Tubtiang**

Manuscript received November 20, 2015
Revised December 15, 2015

ABSTRACT

Digital Economy is under the development worldwide. The key driver is the internet which becomes part of our life. The internet especially mobile broadband users are in continuous growth year by year. This technology helps individuals and communities connected anywhere and anytime. This study is a quantitative research aiming to discover the factors which are driving Thailand's Digital Economy success. PACE (Public-Academic-Community-Enterprise) Model has been newly proposed. The study used the survey method to gather information from respondents in the form of questionnaire. All the questions shown in the questionnaire are based on the objective of this study. The target population is the interested group who attended in the seminar on "Digital Economy and Thailand Future" held by GMI (Graduate School of Management and Innovation) in March 2015. The Five-Point Likert Scale is framed as the indicator for measuring the level of satisfaction. Additionally, this research used Statistical Package for the Social Sciences (SPSS) version 17.0 as the statistical instrument in order to analyze the collected data. Descriptive statistic and multiple regression are used for data analysis. The result from hypothesis testing has revealed that public, academic, community and enterprise have positive affect to Thailand's Digital Economy prosperity. The result from study, researchers found that academic is the most important factor followed by public, enterprise and community respectively.

Keywords: *Digital Innovation, Digital Technologies Management, Smart Thailand, Digital Economy, Digital Transformation*

1. INTRODUCTION

At present, the world is in the information era which may be called the Third Wave [1]. As illustrated in Fig. 1, Toffler named Agriculture Era, the First Wave. The Second Wave was Industrial Era. Information Era would be classified into analog and digital ages. As far as Digital age is concerned, one may also divide it into three stages where;

Naphawan Meesri and Arnon Tubtiang are with the Graduate School of Management and Innovation, King Mongkut's University of Technology, 126 CB5 8th Floor, Pracha-Utid Road, Bangmod, Thungkru, Bangkok 10120

1) Digital 1.0 is mainly based on Web 1.0, however, 1G (First Mobile Generation) may be used for first/last mile communication,
2) Digital 2.0 is based on Web 2.0 together with 2G (Second Generation of Mobile Evolution),
3) Digital 3.0 is based on Web 3.0 and it may incorporate with 3G (Third Mobile Generation) and more advanced such as 4G, LTE.

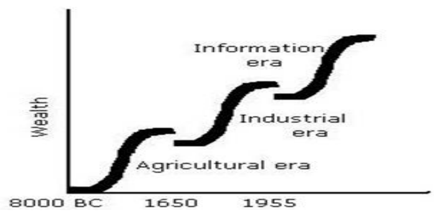


***Fig. 1** World Evolution (Source: Toffler, 1981)*

Thailand has a national ICT policy framework targeted for 2020, in which Broadband and ICT Infrastructure is one main initiative of ICT infrastructure as illustrated in Fig. 2 [2], [3].

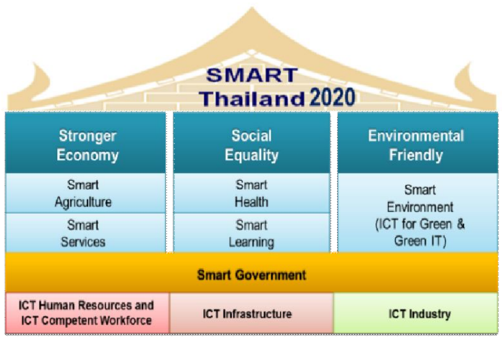


***Fig. 2** Thailand ICT Policy Framework 2020 (Source: MICT, May 2011)*

At present, Thailand is in the implementation of SMART Thailand 2020 which is the ICT Policy Framework targeted for the year 2020. Moreover, in January 2015, the Government endorsed new draft bills to promote ***Thailand's Digital Economy (DE)*** and submitted them for approval by the Senate. The results are awaiting. In mean time, the Government also declared the national target for the Year 2020 of all sectors not only ICT one. ***It is named "Thailand 2020" with the goal of "Stability, Prosperity and Sustainability".*** As known, the internet becomes more imperative for smart service and communication. Most of all services combine the traditional service into internet. The National Electronics and Computer Technology Center (NECTEC) found that the numbers of Thailand internet users are also dramatically increasing from 2,300,000 in 2000 to 26,140,473 in 2013 [4]. Therefore, many enterprises use the internet and cyber space to reach their customers in everywhere at any time.

Thus, this study's intention is to explore the effect of four independent factors which are 1) public, 2) academic, 3) community and 4) enterprise that contributing to Thailand's Digital Economy success.

2. MATERIALS AND METHODS

2.1 Concept of Digital Economy (DE)

First DE idea was from the book "The Digital Economy; Rethinking Promise and Peril in the Age of Networked Intelligence" by Don Tapscott in the year 1995. *Tapscott published the newest version in 2015 as Anniversary Edition-After 20 years* [5], *a New Look Forward. He described the Age of Networked Intelligence as an all encompassed and revolutionized phenomenon fueled by the convergence of advancements in human communication, computing (computers, software, services) and content (publishing, entertainment and information providers), to create the interactive multimedia and the information highway. Four strategies that rules today's leadership: the technological revolution, the Net Generation, and the economic and social revolution. DE is not about networking of technology but the networking of humans through technology who can now combine their knowledge and creativity in order to create new social norms on wealth creation and social development."*

Later in 2013, Eric Schmidt, Executive Chairman of Google launched the book *"The New Digital Age; Reshaping the Future of People, Nations and Business"* described DE as follows [6];

"1) Through the power of technology, age-old obstacles to human interaction, like geography, language and limited information, are falling and a new wave of human creativity and potential is rising.

2) Mass adoption of the Internet is driving one of the most exciting social, cultural and political transformations in history, and unlike earlier periods of change, this time the effects are fully global.

3) Never before in history have so many people, from so many places, had so much power at their fingertips.

4) And while this is hardly the first technology revolution in our history, it is the first that will make it possible for almost everybody to own, develop and disseminate real-time content without having to rely on intermediaries."

From 1990s, several countries or group of countries declared their own frameworks/definitions as cited bellows;

1) EU (European Union) [7]; "The Digital Agenda proposes to better exploit the potential of Information and Communication Technologies (ICTs) in order to foster innovation, economic growth and progress by 2020" in 6 pillars; 1) Digital single market, 2) Interoperability and standards, 3) Trust and security, 4) Fast and ultra-fast internet access, 5) Research and innovation, 6) Enhancing digital literacy, skills and innovation and 7) ICT-enabled benefits for EU society,
2) OECD [8, 9]; Digital Economy Agenda promoting ICT in SMEs "ICT, E-BUSINESS AND SMEs by emphasizing "issues for governments are to foster appropriate business environments for e-business and ICT uptake (*such as* to diffuse broadband, enhance competition), and target programs to overcome market failures to the extent that they are needed in particular areas (*such as* skill formation, specialized information)."
3) Australian Government [10, 11]; Digital Economy as "the global network of economic and social activities that are enabled by platforms such as the Internet, mobile and sensor networks".
   "Australia's future prosperity depends on how effectively we take advantage of such advances: how effectively we become a digital economy. Advancing Australia as a Digital Economy is an update of The Government's 2011 National Digital Economy Strategy the 2011 NDES, building on the 2011 NDES, and laying out the next steps towards delivering our 2020 vision." (Minister of Broadband, Communications and the Digital Economy, Australian Government, 2013)
4) iDA (Singapore's Digital Regulator) [12]; "There is no authoritative definition for the Digital Economy although the term has been in use since the 1990s. Most definitions of the Digital Economy will expand beyond just the Internet Economy (economic value derived from the Internet) to include economic and social activities resulting from other information and communications technologies (ICT)"
5) Canada [13]; Industry Minister James Moore unveiled Digital Canada 150, targeted for 2017 as follows; 1) Connecting Canadians, 2) Protecting Canadians, 3) Economic Opportunities, 4) Digital Government และ 5) Canadian Content, an ambitious path forward for Canadians to take full advantage of the opportunities of the digital age.
6) Malaysia [14]; Digital Malaysia would like to achieve in bringing in ICT for country

development. By 2020, Malaysia will change in the following way; 1) From Supply to Demand Focused, 2) From Consumption to Production and 3) From Low Knowledge to High Knowledge Value-Add

Moreover, DE may be named by several names such as the economies of the digital age, the second economy, the new economics of money, Digitization for economic growth and jobs creation, the apps economy, the social economy, IoT (Internet of Things) and Big Data economy, Data driven economy, the e-tail revolution, the exploding mobile market.

2.2 Thailand's Digital Economy

The Ministry of ICT (MICT) of Thai Government has committed to push the Digital Economy Policy Framework so as to bridge the Digital Divide and modernize the country for the advantage of all aspects of the Thai economy and society recognizing the importance of digital technologies which shall impact and make changes everywhere around the planet of borderless and of big data with easier and faster access through the net. Thailand's digital economy and society framework targeted for a smart and knowledge economy. It depends on five supporting pillars [15, 16].

1) Hard Infrastructure: focuses on reliable networks with enough capability and coverage. The National Broadband Initiative (NBI) proposes to pool along existing network resources that belong to state enterprises and government agencies as non-public organization for additional economical resource. These initiatives also aim to extend investments in knowledge centers by increasing international gateway capability.

2) Service Infrastructure: means infrastructure that allows service innovations in both government and business sectors promoting platforms which will enable knowledge from everywhere to form innovative services. As far as Government is concerned, government knowledge shall be going to be open and integrated through digital government service of which the first goals are supply paperless, one-stop, citizen-centric service etc.

3) Soft Infrastructure: enables and ensures secure and trustworthy digital transactions. New or updated laws and rules are being enacted, particularly to enhance user privacy protection and security.

4) Digital Economy Promotion: aims to make awareness of Digital Opportunity to Thai citizen. It may be through digital business system promotion, particularly the SMEs which composed of almost 97 percent of all firms to be more competitive. Digital commerce shall be necessary tools to bring the SMEs and OTOP (One Tambon One Product) merchandise into world market. Capability building such as digital entrepreneurship, e-commerce, and digital selling necessary to realize a sustainable economic development.

5) Digital Society: aims to bridge digital gaps between rural and urban, riches and poor, women and men, underprivileged and privileged to become a digital society. Equal access will be achieved by means of universal digital inclusion accesses to daily life service such as lifelong education, digital healthcare, digital collaboration etc.

2.3 Theories

a) The Triple Helix is that "the potential for innovation and economic development in a Knowledge Society lies in a more prominent role for the university and in the collaboration of elements from 1) university, 2) industry and 3) government to generate new institutional and social formats for the production, transfer and application of knowledge" [17].

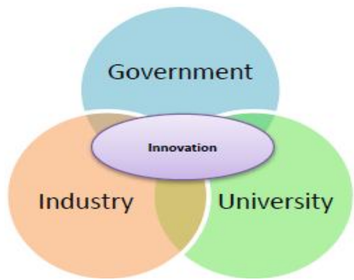


Fig. 3 *Triple Helix Theory (Source: Etzkowitz and Leydesdorff, 1995)*

b) However, in the current context of DE, there are more interested issues than three parameters mentioned above such as society or community likewise. Table 1 summarized parameters which shall contribute to knowledge economy with stability, prosperity and sustainability.

Etzkowitz and Leydesdorff, 1995 [17] researched The Triple Helix as a model for innovation studies and concluded that a variety of ideas are planned for modeling the transformation processes in university-industry-government relations. National systems of innovation [4] are compared with regional systems. A minimum of three main perspectives of the Triple Helix model were known.

Leydesdorff, 2010 [18] has study The Knowledge-Based Economy and also the Triple Helix Model as within the Triple Helix model of the knowledge-based economy, the most establishments have first been outlined as university, industry, and government.

2.4 Research Model

This is a quantitative research. The questionnaire has been distributed to a group of 200 persons who were interested and participated in the "GMI Seminar on Digital Economy and Thailand Future" held in Bangkok, Thailand on Saturday 23rd March 2015. The responses were back from 142 persons which pushed the confidential level to 95 percent [19]. Before proceeding the questionnaire to the interested group of DE, it was test all items through SPSS program and obtained Cronbach's Alpha bigger than 0.7 meaning that the questionnaire was reliable and valid for this research.

***Table 1** Summary of Independent Parameters*

Independent Parameter	Etzkowits and Leydesdorff (1995)	Leydesdorff (2010)	Thai Parliament (2015)	Thai Ministry of ICT (2015)	Industry Promotion Department (2015)	This Research
Public	√	√	√	√	-	√
Academic	√	√	-	-	-	√
Community	-	-	√	√	-	√
Enterprise	√	√	-	-	√	√

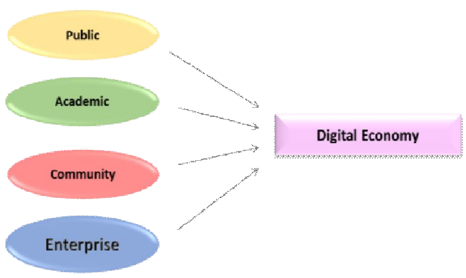


Fig. *4 PACE Model*

2.5 Factor Affecting Digital Economy Prosperity

2.5.1 Public/Government Perspective

The public/government perspective focused on following issues; Digital Government, Policy & Regulation, Law Enforcement, Balance of Security & Privacy, Open Data Policy, Infrastructure including National Broadband Network (NBN) both Fixed Broadband and Mobile Broadband.

A view of the public, including the government. The state has been concerned of the two technologies, Big Data and Internet of Things (IoT) [20]. However summary Identification Public / Government are: 1) Digital Government: The government vigorously promoting. To adjust to the digital services in a professional manner. 2) Policy & Regulation: Thailand government has a solid policy concrete in the digital economy. Goals by 2020. Thailand is Stability, Prosperity and Sustainability. 4) Balance of Security & Privacy. 5) Open Data Policy: To enhance the transparency 6) Infrastructure: It links all the sectors together as the foundation of Networked Intelligence

2.5.2 Academic/University Perspective

A view of education, agencies involved in the education of the country. Influencing the development of the country and reprogram. Economy and Society In the following dimensions:

- The academic/government perspective focused mainly on Knowledge and skills Development,
- Research and Development (R&D),
- Advisory/Consultancy,
- Brain Pool,
- ICT skills in compulsory schooling,
- Framework to encourage ICT skill formation at higher levels, in vocational training and in ongoing lifelong learning,

UNESCO [21] recommended a framework for 21st Century skills in 2010 in following items; 1) Learning and innovation skills, 2) Life and carrier skills, 3) Information, Media and technology skills และ 4) Core subjects and 21st century themes. UNESCO also emphasize on **"Digital Literacies"** as shown in Fig.5.

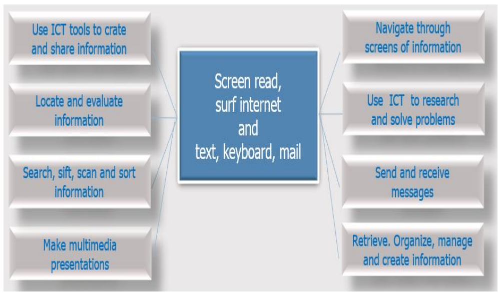


***Fig. 5** Digital Literacy Ability (Source: UNESCO (2010)*

2.5.3 Community/Society Perspective

E. Schmidt, Executive Chairman of Google revealed the New Digital Age as Reshaping the Future of People, Nations and Business in following; 1) the future of identity and citizenship, 2) the future of state, 3) the future of revolution, 4) the future of terrorism, 5) the future of conflict, combat and intervention and 6) the future of reconstruction as well as Cross-Cultural, Multi-national and Borderless. This Community perspective may be described as examples below;

1) Digital Healthcare is to bridge the gap of healthcare between urban and sub-urban and rural areas by maintaining a long distance via video conference as well as wearable devices,
2) Digital Energy aims to the transmission of electric energy more efficiently via the Digital Grid,

3) Digital Agriculture or Smart Farm promotes agriculture products more efficiently, cost effectively, safe products etc. Some digital technologies may be implemented such as sensors to control the levels of moisture, temperature, sunlight, fertilizer and so on.
4) Digital Transportation such as Intelligent Transport System may be introduced for more driving safety. New innovative shall be deployed for example unmanned car, UBER application, GRAB Taxi, Google MAP.
5) Digital Marketing with Social Media shall be a new imperative channel to provide incentives for the purchase of selected goods.
6) Digital Banking transactions may be including e-Money embedded in Smart Phone etc.

2.5.4 Enterprise/Organization Perspective

Digital Organizations including large and small and medium size are essential for future business sustainability. Business needs to transform into new digital paradigm at least in three dimensions [22];

1) Customer Experience Transformation: At present, most customers are digital. Thus, firms can join together to create value in the Value Co-creation. Consisting Customer Understanding, Top-Line Growth, Customer Touch Points.

2) Operational Process Transformation: Firms integrate digital technologies into the process. The organization shall be more efficient as well as reduce operating costs. Firms may transform through the implementation of ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) and SCM (Supply Chain Management). It is also the use of Digital Innovation in Process Digitization, Worker Enabler and Performance Management.

3) Business Models Transformation, organizations and enterprises in the same business are forced to consider the digital opportunities and new challenges. It may be consisting of Digitally Modified Business, New Digital Business and Digitally Globalization.

In this study, a set of questionnaires was developed to gather data from the groups of respondents. The researchers separated the research instruments which is a closed end questionnaire into 3 parts. Part 1 is respondents' profile. In part 2, there are four main independent variables which are Public, Academic, Community and Enterprise which are the factors affecting the prosperity of Thailand DE. In Part 3, Prosperity is the dependent variable together with open-end question. The researchers used the 5-point Likert scales to measure respondents' information.

Descriptive analysis had been use to describe the brief information from the data collected, which is normally used for analyzing demographic factors. Moreover, multiple regression analysis was used to predict or explain a dependent variable based on four independent variables.

2.6 Research hypotheses

According to the conceptual framework, this study has in total four hypotheses as the follows:-

H1: Public expectancy affects DE prosperity,
H2: Academic expectancy affects DE prosperity,
H3: Community expectancy affects DE prosperity,
H4: Enterprise expectancy affects DE prosperity,

3. RESULTS AND DISCUSSION

This is a quantitative research. The questionnaire has been distributed to a group of 200 persons who were interested and participated in the "GMI Seminar on Digital Economy and Thailand Future" held in Bangkok, Thailand on Saturday 23rd March 2015. The responses were back from 142 persons which pushed the confidential level to 95 percent [23]. Before proceeding the questionnaire to the interested group of DE, it was test all items through SPSS program and obtained Cronbach's Alpha bigger than 0.7 as illustrated in Table 2 meaning that the questionnaire was reliable and valid for continuing this research. The researchers separated the research instruments which is a closed end questionnaire into 3 parts. Part 1 is respondents' profile. In part 2, there are four main independent variables which are Public, Academic, Community and Enterprise which are the factors affecting and driving the prosperity of Thailand DE. In Part 3, it is Prosperity which is the dependent variable. The researchers used the 5-point Likert scales to measure respondents' information. There is also open-end question where researchers welcome all comments, suggestions from the respondents.

Descriptive analysis had been use to describe the brief information from the data collected, which is normally used for analyzing demographic factors. Moreover, multiple regression analysis was used to predict or explain a dependent variable based on four independent variables.

Respondents are 54.23 % female, age of 20-30 years old (71.83 %), single status (88.03 %), bachelor degree (82.39 %) and employee in private firms (40.14 %) with the salary of 10,000 – 20,000 THB (33.10 %). In case of usage internet frequency, most of them (61.27 %) use more than 2 hours. Their objectives for use the internet are as follows; 1) Learning (24.65 %), 2) Work and Business (21.83 %), 3) E-mail (19.72%), 4) Chat (11.97 %), 5) Entertainment (9.15%), 6) Shopping (8.45%) and 7) Information (4.23 %).

Table 2 *Summary of Reliability Analysis*

Variables	Cronbach's Alpha	No. of Items
Public	0.886	8
Academic	0.894	5
Community	0.941	4
Enterprise	0.751	3
Digital Economy	0.921	4

Table 3 *Result of Adjusted R Square*
Model Summary

Model	Adjusted R Square
1	0.411

Table 3 shows coefficient of determination or the R Square is equal to 0.411 or 41.1% that means four independent variables (P-A-C-E) may drive the dependent variable (Digital Economy Prosperity) at 41.1%. There are some more other variables to be explored in the future research.

Table 4 *ANOVA Test Result*
ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25.503	4	6.376	23.941	.000
	Residual	36.485	137	.266		
	Total	61.988	141			

The above Table 4, ANOVA test shows the regression coefficients of four variables are independent because of Sig being equal to 0.000.

Coefficients in Table 5 above shows the test results for each variable. All variables (Public, Academic, Community and Enterprise) are the sig., because they are less than 0.05. Thus that means the confirmation of the hypotheses one to four (H1, H2, H3 and H4).The variable Public, Academic, Community and Enterprise are positive correlation with the Digital Economy Prosperity as shown in Table 5 below.

Table 5 *Result of Multiple Regression Analysis*
Coefficients [a]

Model	Unstandardized Coefficients		Sig.
	B	Std.Error	
(Constant)	.638	.369	.086
Public	.205	.087	.020
Academic	.381	.094	.000
Community	.136	.069	.050
Enterprise	.159	.068	.021

a. Dependent Variable: Thailand DE Prosperity

Table 6 *Hypotheses Test*

hypotheses	Explanation	Results
H1	Public related to driving the Digital Economy	Confirmed
H2	Academic related to driving the Digital Economy	Confirmed
H3	Community related to driving the Digital Economy	Confirmed
H4	Enterprise related to driving the Digital Economy	Confirmed

The regression equation shall be formulated as follows:

$$DE = 0.677 + 0.205\ PUB + 0.381\ ACA + 0.134\ COM + 0.152\ ENT$$

Where: DE is Digital Economy Prosperity,
PUB is Public Factor,
ACA is Academic Factor,
COM is Community Factor,
ENT is Enterprise Factor.

From Table 5, Academic factor is driving the Prosperity of Digital Economy with the highest importance (at the Beta value of 0.381). The second most impact factor is Public with the Beta value of 0.205. Then, No. 3 is Enterprise with the Beta equal to 0.152. And lastly, the Community is the least impact factor to Thailand's Digital Economy at a Beta value of 0.134.

This research results would be analyzed and confirmed by the recommendations and comments from respondents who were the interested group attending to GMI Seminar on Digital Economy and Thailand Future [24]. The concerns of the group are most related to Academic and Public Factors the same as results from the regression test revealed as follows;

1) Brain Pool and workers with good ICT skills should be developed in earliest time,
2) Parents and Teachers should be trained not only children so that they could coach children effectively with good usage of Digital. Some children still use the internet in negative side,

3) It is a good Public initiative in promoting DE policy; especially for 1) Enabling competitive advantage to Thai Enterprise, 2) Bridge the Divide in accessing to Digital Content, 3) Lacking of Public continuity and cooperation between Public and Enterprise which result to unachievable targets,
4) Public should boost the DE awareness more to stakeholders,
5) Public should make clearer and more concretely in DE policy especially the ICT skills development, and
6) It is lacking of continuous policy evaluation, DE is good in planning but weak in implementation. Government and private enterprise should sacrifice and contribute more to bridge the gaps.

4. CONCLUSIONS

This study reveals several affecting factors that related to driving Digital Economy in Thailand. In order to driving Digital Economy for development the economy and society in Thailand, academic (0.381) is most encouraged. Secondly, public (0.205) is also recommended. Later, enterprise (0.159) and community (0.136) are also considered. From the result, one may formulate a relationship equation (DE = 0.638 + 0.205 PUB + 0.381 ACA + 0.136 COM + 0.159 ENT) for forecast to driving Digital Economy in Thailand.

In the hypothesis testing, hypotheses one, two, three and four were analyzed by using Multiple Regression Analysis to explore the direction of the variables. Moreover, the multiple regression analysis was used to examine the factor

This study discloses several affecting factors that related to move forward Thailand's Digital Economy. New tool named "P-A-C-E" Model was proposed and validated through an interested group composing experts and individuals who attended the seminar on "Digital Economy and Thailand Future" held by Graduate School of Management and Innovation (GMI), King Mongkut's University of Technology Thonburi (KMUTT) in March 2015.

Base on the result from hypotheses test, independent variables which are academic, public, enterprise and community were found to have positively related to the driving of Digital Economy. This study reveals several affecting factors that drive Digital Economy in Thailand, 1) Academic (0.381) is the most impact factor, secondly, 2) Public (0.205) is also significant. Later, 3) Enterprise (0.159) and Community (0.136) are less affecting factors respectively. From the result, one may formulate a relationship equation (DE = 0.638 + 0.205 PUB + 0.381 ACA + 0.136 COM + 0.159 ENT) for forecasting the success of Digital Economy in Thailand. Recommendations are given for improvement of the policy along the way to target. Test result shows that P-A-C-E have the contribution of 41.4 percent which could be considered major impacts. However, this equation may be improved further for real implementation through deeper investigation.

REFERENCES

[1] A. Toffler, The Third Wave, published by A Bantam Book, New York, USA, 1981,
[2] Ministry of Information and Communication Technology, Thailand, "*ICT Policy Framework 2020*, May 2011,
[3] A. Tubtiangand and S. Pipatpanuvittaya, 2014, "A Study of Factors that Affect Attitude toward Deploying Smart-Farm Technologies in Tanud Subdistrict, Damnoen Saduak District in Ratchaburi Province", *ICAAI2014*, November 2014,
[4] Network Electronics and Computer Technology Center (NECTEC), Internet Information Research Network Technology Lab [Online], Available: http://internet.nectec.or.th/webstats/home.iir?Sec=home [4 December 2015].
[5] D. Tapscott, the Digital Economy: Rethinking Promise and Peril in the Age of Networked Intelligence, McGraw-Hill, 2015,
[6] E. Schmidt and J. Cohen, "The New Digital Age: Reshaping the Future of People, Nations and Business", Alfred A.Knopf, 2013,
[7] European Commission, "Digital Agenda in the Europe 2020 strategy", available at https://ec.europa.eu/digital-agenda/en/digital-agenda-europe-2020-strategy (19 December 2015),
[8] Directorate for Financial and Enterprise Affairs Competition Committee, OECD, "the Digital Economy 2012", the Hearings, 7 February 2013,
[9] OECD, "ICT, E-BUSINESS AND SME", 2004,
[10] Department of Broadband, Communications and the Digital Economy, Australia, "National Digital Economy Strategy", 2011,
[11] Department of Broadband, Communications and the Digital Economy, Australia, "Advancing Australia as an Digital Economy: an Update to the National Digital Economy Strategy", 2013,
[12] the infocomm Development Authority (iDA), Sigapore, "the New Economy", Section 10, pp. 2-49, 24 April 2012,
[13] Digital Canada 150, Ministry of Industry, 2014,
[14] K. Pooparadai, "Moving Organization through Digital Economy Policy", the Office of Permanent Secretary of ICT Ministry, 3rd December 2014,
[15] Ministry of Information and Communication Technology, 2015, "Digital Economy" [online], Available: http://www.mict.go.th/view/1/Digital%20Economy [12 December 2015].
[16] A. Kiatsarapipop, "Digital Economy: New Economic Policy", Journal of Academic Focus, Office of Secretariat of Parliament, pp.1-15, March 2015,
[17] L. Leydesdorff and H. Etzkowitz, "The Triple Helix as a model for innovation", Science and Public Policy, vol.25, No.3, pp. 195-203, 1995,
[18] L. Leydesdorff, "The Knowledge-Based Economy and the Triple Helix Model", Amsterdam School of Communications Research, University of Amsterdam, pp. 3-8, 2010,
[19] W. G. Cochran, Sampling Techniques, 2nd Ed., New York: John Wiley and Sons, Inc., 1963,
[20] World Economic Forum (WEF), "The Global Information Technology Report (GITR)", 2014,
[21] UNESCO, "ICT Transforming Education: the Regional Guide", 2010,
[22] The MIT Center for Digital Business and CAPGEMINI Consulting, Digital Transformation: A Roadmap for a Billion-Dollar Organizations, 2011,
[23] T. Yamane, Statistics: An Introductory Analysis, 2nd Ed., New York: Harper and Ro, 1967,

[24] GMI, Seminar on "Digital Economy and Thailand Future", Bangkok, March 2015,

Naphawan Meesri received B.Eng in Telecommunication Engineering from Rajamangala University of Technology Thanyaburi in 2011. She is currently pursuing M.Sc. in Telecommunication and Broadcasting Management from King Mongkut's University of Technology Thonburi. She is also working as an engineer at TOT Public Company Limited .

Dr.Arnon Tubtiang graduated B.Eng (Telecommunication) from King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand in 1985. He got scholarship to pursue DEA degree (Computer Systems : major in Computer Network) and Doctorate degree (Computer) from Pierre-Marie Curie University, Paris, France in 1990 and 1993 respectively. He received the certificate of Advanced Management Program (AMP) from Harvard Business School (HBS), USA in 2006. Moreover, he was the Chair of APEC Telecommunication and Information Working Group (APECTEL) during 2007 and 2009 as well as the President of TOT (a state owned telecommunication operator) during 2011 and 2012. At present, he is the Program Chair of Telecommunication and Broadcasting Management in Graduate School of Management and Innovation (GMI), King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand.

Gradually Adopted Flipped Classroom Teaching Technique to a Traditional Lecture-Based Teaching in an Electrical Engineering Course

Preecha Kocharoen and **Sirinthorn Sinjindawong**

Manuscript received December 11, 2015
Revised December 20, 2015

ABSTRACT

This article introduces teaching techniques by using a gradually adopted flipped classroom. The objectives of this study are 1) to study teaching techniques by using a gradually adopted flipped classroom with students from the electrical engineering course and 2) to compare a learning outcome of students between a 25% – 50 % gradually adopted flipped classroom teaching technique and a 75% – 100 % gradually adopted flipped classroom teaching technique. The sample used two groups of students, 41 and 36 students, from the electrical engineering course, EEG371-principle of communication, in semester 1/2558. The instruments used in this research were screencast teaching video, social network and an online test. The results showed that a flipped classroom technique used in conjunction with a traditional teaching approach could personalize learning so that it's tailored to student's individual abilities. In addition, learners with different abilities would be able to learn at their own speed. Moreover, a learning outcome of students from two groups, a 25% – 50 % gradually adopted flipped classroom of students group 1 and a 75% – 100 % gradually adopted flipped classroom of students group 2 are compared. The result shows that students group 1 could get average score 5.8 while students group 2 could get average score 8.1 from 10. It can be seen that the higher percentage of adopted flipped classroom performs better than the lower percentage of adopted flipped classroom.

Keywords: *Flipped Classroom, Student Learning Outcome, Teaching Technique*

1. INTRODUCTION

DEVELOPMENT of teaching continuously for innovation to promote student learning outcome of specific communication on an engineering course by attractive activities with the e-learning system (Kocharoen, 2014) has been implemented in the class. The knowledge gained from the project that mainly constructs wireless sensor network transceiver modules is presented in the class to motivate students. Moreover, e-learning and online quizzes as activities to supplement the classroom have been used. The results from the mentioned project works which used the competition technique or activities-based technique show that they can attract the attention of students although learning contents are complex calculations or hard to understand. On the other hand, extra activities have been added to the class while the class duration is still the same, three hours per week for 15 weeks. This may cause an increase in the work load to learn and add extra responsibility to students throughout the class period. As a result, students who learn more slowly than their friends in class cannot catch up the class. The teacher who is responsible for teaching also needs to teach classes with a complete learning content that is required by the council of engineers. If teaching in the same format, then focus on teaching theory and methods of computation as the main focus. The extra activities and demonstrations are also presented or the learning will not bear fruit for students who learn more slowly than other students. In this paper, we present teaching technique which is the gradually adopted flipped classroom to promote the learning outcome of students in the course EEG371 Principles of Communication which is a specific course for electrical engineering and applied electronics, Faculty of Engineering, Sripatum University. The project was carried out in the semester 1/2558.

2. THE PURPOSE OF THE STUDY

1) To implement teaching techniques by using a gradually adopted flipped classroom with students from the electrical engineering course, and

2) To compare a learning outcome of students between a 25% – 50 % gradually adopted flipped classroom teaching technique and a 75% – 100 % gradually adopted flipped classroom teaching technique.

3. THE SCOPE AND CONCEPT OF THE STUDY

The subjects were two groups of students, 41 and 36

Preecha Kocharoen is with the Department of Electrical Engineering and Applied Electronics, Sripatum University, Bangkok, Thailand (e-mail: preecha.ko@spu.ac.th).
Sirinthorn Sinjindawong is with the Teaching and Learning Support and Development Center, and the Philosophy Program in Educational Administration at Graduate College of Management, Sripatum University, Thailand (e-mail: sirinthorn.si@spu.ac.th).
*This work was presented at the 1st ASEAN-ROK e-Learning Forum hosted by ASEAN Cyber University in Seoul, Replublic of Korea on 8 – 9 Dec. 2015.

students, who studied in EEG371 Principle of Communication in 1/2558 semester, Department of Electrical Engineering and Applied Electronics, Faculty of Engineering, Sripatum University in separate classes. Students group 1 was applied a 25% – 50 % gradually adopted flipped classroom while students group 2 was applied a 75% – 100 % gradually adopted flipped classroom. The instruments used in this research were screencast teaching video, social network and an online test. The conceptual frameworks of the study are shown in Fig. 1 and Fig. 2. Fig. 1 shows the traditional teaching model for a lecture-based teaching technique that a lecturer only presents learning materials in front of the classroom and allows students convert studying contents into the knowledge at home. On the other hand, the flipped classroom technique moves the learning materials e.g. screencast videos outside the classroom and allows variety activities that can reinforce learning in the classroom. In Fig. 2, four gradually adopted flipped classrooms, which are 25%, 50% 75% and 100%, are shown. The more percentage of adopted flipped classroom means the less classroom time spends in the traditional lecture-based teaching technique.

at home inside the classroom

(a) a lecture-based teaching technique

outside the classroom inside the classroom

(b) a flipped classroom teaching technique

Fig. 1 *Difference between teaching techniques.*

4. FLIPPED CLASSROOM LEARNING TECHNIQUES

Two teachers in the United States, Jonathan Bergman and Aaron Sams, want to help low-ability students in their class who are unable to keep up with friends or other students who miss classes. They thought taking the time to convert learning content into essential knowledge that is linked to real life is important to students thus they provide valuable time for students in the classroom for converting learning contents effectively. After that they wrote the techniques and approaches for teaching titled Flip Your Classroom: Reach Every Student in Every Class Every Day (Bergmann & Aaron, 2012). The different between a lecture-based teaching technique and a flipped classroom teaching technique are shown in Fig. 1(a) and Fig.1(b) respectively. If students have learned in class from teaching, then they take the learnt knowledge back home and sometime students may not convert learning contents correctly. On the other hand, the flipped classroom, teachers use ICT e.g. screencast video of them teaching the learning content which is taught in regular classes and then puts it on the Internet or online. The online screencast videos allow students to learn outside the classroom with the ability to repeat or pause the video if they don't understand. Some learning topics that students don't understand clearly, they can take notes and then ask the teacher during the class time. In the class, the students do not need to take the time to learn the subject since the study was done before. Classroom time can be used as a greater value to students. Teachers can process learning activities appropriate to the abilities of students so that it's tailored to student's individual abilities. In addition, learners with different abilities would be able to learn at their own speed. Students who learn slowly are grouped and get attention. Teacher teach the class with the same speed and the same content, students who learn slower or are absent will not be able to catch up on classes. A flipped classroom technique used in conjunction with a traditional teaching approach could allow teachers to operate and guide creative classroom activities that fit each student.

(c) 75% (d) 100 %

Fig. 2 *Concept study of teaching techniques using a gradually adopted flipped classroom.*

5 LEARNING AND THE USE OF ONLINE LEARNING

This Principles of Communication course is a theoretical course in semester 1/2558. Online learning (E-Learning) has been implemented to help in the teaching. The system is supported by Sripatum

University (http://elearning.spu.ac.th/) online learning system. The use of electronic media via the Internet can facilitate the students learning from the lessons provided via the Internet anywhere and anytime on demand. Assignments and tests can be included into the system. This system also is a communications channel between the students to collect reports or show scores as well. Figure 3 shows the page of the online e-learning system. The University e-learning system can connect to YouTube for ease of viewing screencast videos of the students since YouTube has gained widespread popularity. All screencast videos from the Principles of Communication course for 1/2558 semester have been uploaded to YouTube and are available on url: http://bit.ly/YoutubeEEG371/Lecture as shown in Fig 4.

***Fig. 3** online e-learning system.*

6 THE PROCEDURE OF USING THE FLIPPED CLASSROOM TECHNIQUE

A flipped classroom teaching technique should be gradually adopted and applied into a lecture-based teaching technique. Students group 1 was applied a 25% – 50 % gradually adopted flipped classroom while students group 2 was applied a 50% – 100 % gradually adopted flipped classroom as shown concept study of teaching techniques in Fig. 2. During each week, a minimum amount of change is put into the class e.g. it may take a period of only 30 minutes per class for the flipped classroom technique. In the classroom, activities are reinforced e.g. demonstration, quiz, game, Q&A or mini-project in order to draw interesting from students. These techniques can improve learning ability of students although in some complex and difficult-to-understand topics. On the other hand, the learning period in the class still fixed thus the lectures in front of the class will be reduced or have to make them fast and will left some students who have slow-learning behind. Therefore, students are assigned to watch lectures for online VDO i.e. from Youtube which linked from SPU LMS (Moodle) before normal class which is shown in Fig. 4. This process has to be done at student’s home or at the provided space in SPU library and it is called before-classroom activities. Learning from VDO allows students can learn with their own speed and can be pause and play as many as they want until they can understand the lesson. Another effective activity before-classroom is pre-class quiz, this quiz can implement using SPU LMS and can be configured to allow students attempt twice with random question as shown in Fig. 5.

***Fig. 4** Screencast videos from the Principles of Communication course*

Next, during-classroom activities should begin with listening to the questions that students could not understand clearly from the watched videos. Upon receiving information from the students, the teacher summarizes and explains the learning objectives. Next session is Q&A session that allows each student asks their own question and if anyone in the class can answer one will get the point as shown in Fig. 7 – 8. If no one can answer, teacher will explain that question and the student who ask will get the point. The teacher who supervised the students will be able to solve the misunderstanding immediately. Students who have studied well have fun with the questions and are proud to be praised by the teacher when answering questions correctly. After that teacher will summarize the main idea of this lesson before moving to the next competition which used SNS i.e. Facebook (i.e. http://www.facebook.com/EEG371). This Facebook page was created exclusively for communication with students who enrolled on this course. One of the possible ways to create an activity in the class is to ask and post it to the Facebook page as shown in Fig. 6. Student who can answer the question correctly can gain extra score. Teacher will post the question on the Facebook page. Two kinds of questions that might be posted, simple question and calculating question. The simple questions are used to check that students understand so only a short amount of time is allowed to answer. The calculating question will take more time to solve and will allow students to help each other solve the problems. During this time, the teacher can walk around the room to observe understanding and guide students to solve the question which will help to assist learning for the individual. As a result, students can learn to interpret and understand the questions better. In addition, the use of social media is also useful in sharing how to find answers among students and can be revisited later.

Fig. 7 – 12 show activities during the class time in order to process learning activities that appropriate to the abilities of students. Fig. 7 – 8 show group discussion of student group 1 and student group 2 in the classroom respectively. Fig. 9 shows an example of group presentation from the assigned problem. This activity can specific the problem to each student groups in order to focus on some important topics. In addition, some demonstrations could be shown to students to motivate or inspire engineering sense e.g. base band coding and signal modulation demonstration are shown in Fig. 10 and Fig. 11 respectively. Moreover, one of success activities to gain students' attention during the class is a group quiz competition that is shown in Fig. 12. Students are divided into several groups and each group play quiz game. The group that can correctly answer more quizzes can move to the next heat and the group that can beat all competitors will be the winner.

7 CONCLUSION AND SUGGESTION

The study found that learning outcomes of students from students group 1 was applied 25% – 50 % gradually adopted flipped classroom and students group 2 was applied 75% – 100 % gradually adopted flipped classroom are detailed as follows. The flipped classroom teaching technique intended to modify the classroom to improve the efficiency of student learning. The change of classroom lectures to spend time outside the classroom with screencast videos collected online then changes the content of in-classroom study in understanding knowledge. Furthermore, the use of classroom time for activities appropriate to the learning objectives e.g. some topics may use the same information for all students directly but some students may find it more appropriate if specific information is aimed for individuals. Some objectives may need activities to be created for students to discover, and self-learning experiments. The flipped classroom could create an atmosphere that will help learning be more effective. The teacher will access the student's thoughts in the class by creating a good atmosphere. The important thing to remember is to teach the students responsibility for their own learning outside the classroom. The class must have the flexibility to learn at a speed appropriate to the abilities of the students. This is consistent with Shimamoto (2012) who uses the flipped classroom teaching techniques applied in teaching by supporting the learning process of the students with the use of technology. The researcher increased learning in the classroom to interact and cooperation between the students, and the researcher found that a lesson from the media provided more understanding if there was some examples and application usage. Moreover, the learning outcomes of students from two groups, a 25% – 50 % gradually adopted flipped classroom of students group 1 and a 75% – 100 % gradually adopted flipped classroom of students group 2 are compared. The post-test was used and the results show that students group 1 could get average score 5.8 while students group 2 could get average score 8.1 from 10 and most students who struggled could improve and pass the test. It can be seen that the 75% – 100 % gradually adopted flipped classroom perform better than the 25% – 50 % gradually adopted flipped classroom.

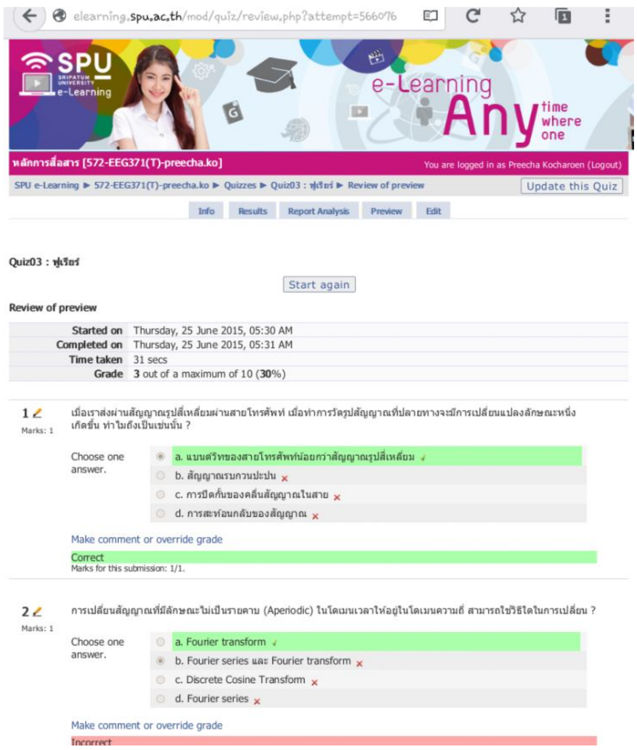


***Fig. 5** an example of online quiz*

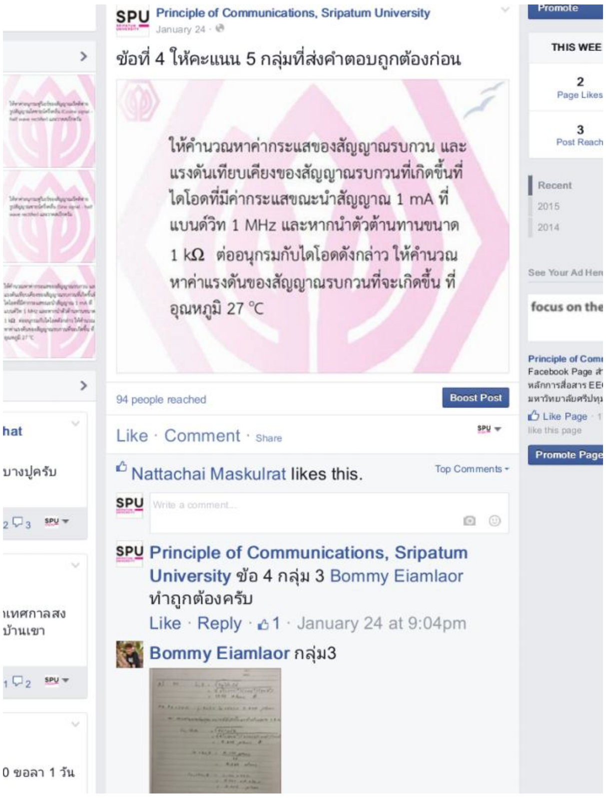


Fig. 6 *an example of Facebook page question*

Fig. 7 *Activity of students group 1 during the class: discussion*

Fig. 8 *Activity of students group 2 during the class: problem solving*

Fig. 9 *Activity of students group 2 during the class: presentation*

Fig. 10 *Activity of students group 2 during the class: coding demonstration*

Fig. 11 *Activity during the class: signal modulation demonstration*

Fig. 12 *Activity during the class: group quiz competition*

Suggestions from the study, teacher should use more modern technology in teaching and learning to meet the interests of the students and teacher also should interact with the students to create a relaxed atmosphere in the classroom to reduce gaps between using online learning outside the classroom and the flipped classroom. At the beginning of class time, there should be the time to inquire about the issue of self-study outside the classroom and examine that students learnt from the screencast video before coming to class or not. Furthermore, students should be classified into groups with different abilities; this could help them to learn from each other. It would also help guide the students with different abilities in their focus.

REFERENCES

[1] P. Kocharoen, "Innovation to Promote Student Learning Outcome of Specific Communication Engineering Course by Attractive Activities with E-learning System," *APHEIT Journal*, vol. 20, no. 2, pp. 124–135, 2014.

[2] B. Jonathan, and A. Sams, "Flip your classroom: Reach every student in every class every day," in *International Society for Technology in Education,* 2012.

[3] D. N. Shimamoto, "Implementing a Flipped Classroom An Instructional Module," in *Proc. 17th Annual TCC Worldwide Online Conference: Emerging Technologies: Trends and Issues.,* 2012. Available: http://etec.hawaii.edu/proceedings/masters/2012/Shimamoto_D.pdf

Preecha Kocharoen has been working as a lecturer with the Sripatum University since 1999. He graduated in B.Eng. (Electrical), M.Eng (Communications), and D.Eng (Telecommunications) on 1996, 1998, and 2005 respectively.

He received best faculty award for young researcher and best faculty award in academic in 2009 and 2013 respectively. He has been serving to several professional organizations for many years including Thai Embedded System Association (TESA) and IEEE ComSoc (Thailand). He is currently an IEEE member and ECTI member.

Sirinthorn Sinjindawong graduated from Faculty of Education Chulalongkorn University, Thailand with Doctoral degree in Educational Measurement and Evaluation in 2010, and master degree major in Educational Measurement from Srinakharinwirot University, Thailand and Bachelor degree major in General Science from Pranakorn Sri Ayutthaya Rajabhat University, Thailand.

She is a director in Teaching and Learning Support and Development Center, and a Lecturer in Doctor of Philosophy Program in Educational Administration at Graduate College of Management, Sripatum University, Thailand.

The Integrated e-Learning and Social Media for Flipped Classroom Approach in Engineering Class

Keerati Chayakulkheeree

Manuscript received December 11, 2015
Revised December 23, 2015

ABSTRACT

This paper presents the experience on the flipped classroom activities in the electrical engineering class, EEG456 Power System Protection and Relay, School of Engineering, Sripatum University, Bangkok, Thailand. In the investigated model, the integrated flipped model using e-Learning system and social media is applied. The Sripatum Campus Management System (SCMS), Sripatum e-Learning system and the social media, which are Youtube and Facebook, are incorporated to others. Therefore, the student information is conveniently managed with the test bank and online assignment system. In addition, the students are closely supervised and encouraged to carry on the learning process and feel free to share their learning outcome. The student satisfaction and learning outcome are used to assess the learning model used.

Keywords: *Integrated learning; flipped classroom approach; e-Learning.*

1 INTRODUCTION

FLIPPED class room is currently an alternative solution tool in nowadays teaching and learning facilitation. The student learning behavior is extremely changed from the earlier day. The flipped classroom approach requires the modern on-line teaching materials, for example, VDO, interactive software, test bank with real-time score responding, and assignments.

Due to the important of problem solving skill in the engineering learning process, the flipped models are interested by many class facilitators. Many flipped engineering classroom models had been proposed by several educational researches, in accordance to class characteristics. For example, Chetcuti, et.al., (2013) presented the development structure and lesson learned during establishing the blended flipped model in the basic engineering classroom. Meanwhile, Vaughan (2014) studied and investigated the flipped model in an introductory teaching course. In addition, Stanley and Lynch-Caris (2014) shared an experience on a method used in Dynamic class that the students are required to view pre-lecture VDOs in prior to the class. The small class size (<20) with flipped approach was implemented and presented by Lemley, et.al., (2013), in the Thermodynamic class. In the later research, Arslan (2015) presented an innovative flipped classroom method to teach the Electromagnetic Field Theory that observably gained the student performance and motivation.

As well, the successful of flipped classroom approach had been reviewed and reported. Kerr (2015) studied the student performances and satisfactions on the flipped classroom reviewed from the existing researches. Most studies reported high student satisfaction and increased performance in the flipped classroom Environments. Nevertheless, the survey of the researches on flipped classroom, conducted by Bishop and Verleger (2013), resulted in that the student perceptions are generally in positive overall. Students tend to prefer in-person lecture but prefer interactive classroom activities over traditional lecture class.

In this paper, the investigation and experience on the integrated flipped model, using e-Learning system and social media, is presented. The method was adopted in the course EEG456 Power System Protection and Relay, Sripatum University. The Sripatum Campus Management System (SCMS), which is the system provide all student information and course detail including grading system, is incorporated with Sripatum e-Learning system. The e-Learning system provides the course content and material including test bank and assignment system. The main social media used are Youtube, for fast VDO link to the e-Learning system, and Facebook, for real-time or near-real-time information and encourage the students' learning process. The method resulted in good students' satisfaction and high increment scores from pre-tests to post-tests.

2 COURSE STRUCTURE

The course EEG456 Power System Protection and Relay consisted of electric power system fault and behavior, protective devices for transmission line and power equipment. The course objectives are in both technical design understanding and engineering computation skill. Therefore, student should be able to explain the protection system for transmission line and power equipment including computation for the

Keerati Chayakulkheeree is with the School of Engineering, Sripatum University, Bangkok, Thailand (e-mail: keerati.ch@spu.ac.th).
*This work was presented at the 1st ASEAN-ROK e-Learning Forum hosted by ASEAN Cyber University in Seoul, Replublic of Korea on 8 – 9 Dec. 2015.

protective equipment characteristics. The assessment processes include understanding and computational skill tests via the questions in test bank, assignments and examinations.

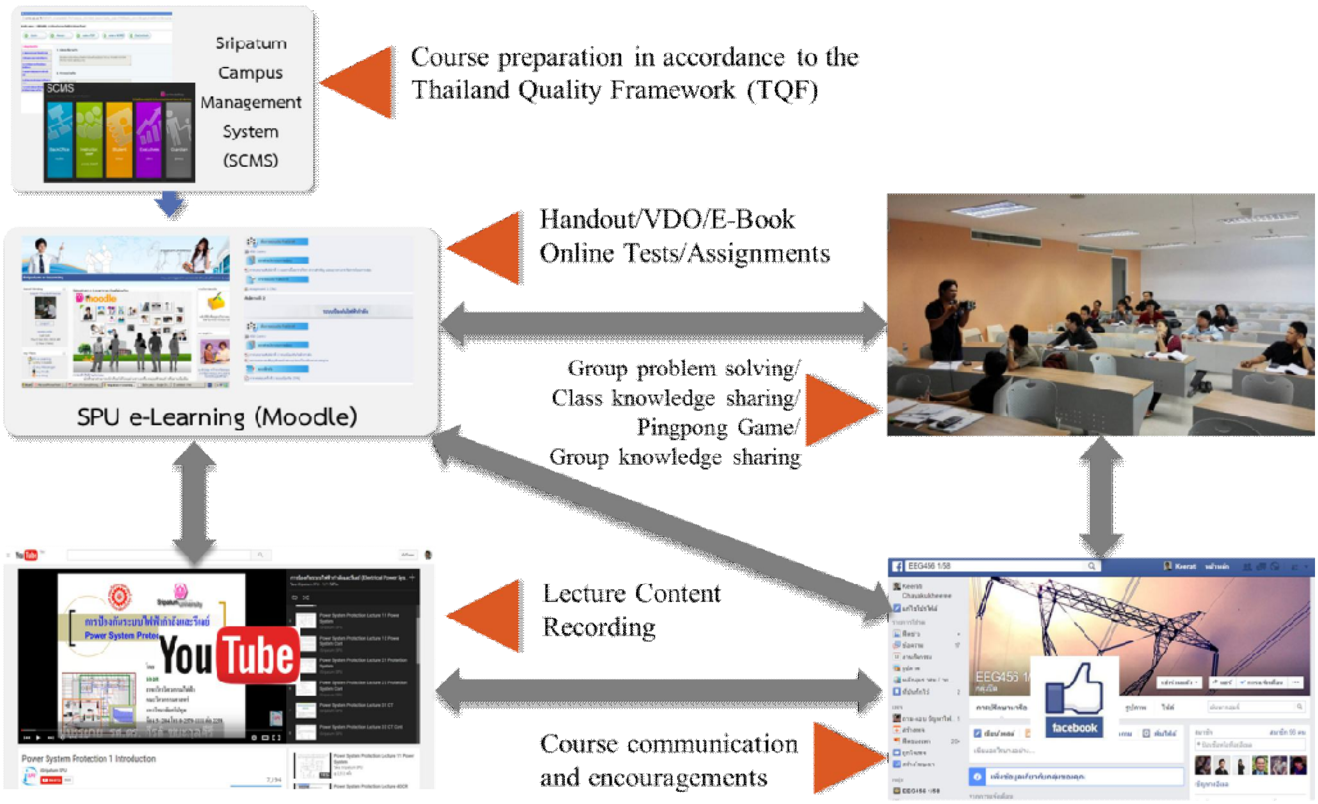


Fig. 1 The integrated model for e-Learning and social media approach.

3 THE INTEGRATED LEARNING MODEL APPROACH

In the integrated learning model, the Sripatum Campus Management System (SCMS), Sripatum University e-Learning System, social media (mainly on Youtube and Facebook) and lecture class are incorporated to others, as shown in Fig. 1. Each component in the integrated learning model has its helpful features for flipped classroom approach. The e-Learning system is mainly used for main communication and providing course materials including assignments and quizzes procedures. Meanwhile, the lecture VDOs are provided in Youtube. In addition, Facebook is used for both group real-time communication and leaving massages, and to encourage the students to learning process.

A. Sripatum University e-Learning System

In Sripatum University, the e-Learning had been adopted in several class and in different natures in accordance to class characteristics. The e-Learning application could be applied in three categories as follows,

- Complimentary - Use of e-Learning resources to compliment knowledge,
- Supplementary - Use of e-Learning to supplement and assist Blended-Learning environment, and
- Replacement - Use of e-Learning in fully online courses.

For the flipped classroom approach, the e-Learning should be fully utilized as replacement e-Learning, so that the students can access to all courseware, VDO, assignment, and quizzes. The e-Learning system is incorporated to the Sripatum campus management system (SCMS) for the students information. The test bank features of e-Learning system, automatic random in questions and choices can be applied. The student can get the individual score information after checking with more than one attempt are possible. The features of the e-Learning are shown in Figs. 2. The feature of screen cast capture of the lecture content and test bank are shown in Figs. 3 and 4.

B. Social Media Utilizations

In addition to the e-Learning system, the social media, which are commonly free communication online tools, could be used for further two-way communication, information, and to encourage the students to learn the course contents.

The social media used in the class are as follows,

- Youtube (www.youtube.com) - for providing the VDO for the student to access anytime and anywhere they feel free to learn.

- Facebook (www.facebeek.com) - for providing the "feel-free" two-way communication between students and class facilitator. In Facebook, the process could be obtained via,
  - Fanpage – which is the page established by the class facilitator and the students are mandatorily click like to the page to follow the class information, andClosed group – which is the group established by the class facilitator and add the students to the group.

Fig. 2 The main page features of the e-Learning system

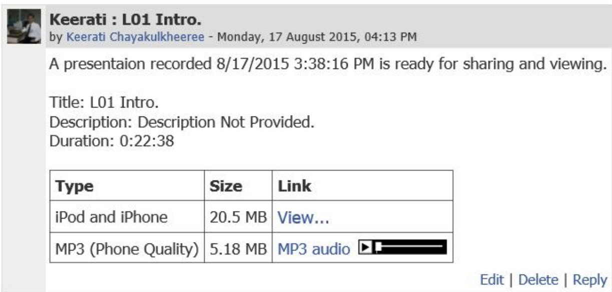


Fig. 3 On-line screen cast VDO and MP3 audio record

The Youtube application can be easily linked or embedded to the e-Learning system and social media with minimum time and storage requirement. The example page is shown in Fig. 4.

Meanwhile, the Facebook applications are shown in Figs. 6 and 7. The Facebook or similar social media can be used for both in and out classroom. In classroom, the social media can be used as gaming tool for answer the questions individually, or as a group. Moreover, in prior to or after class, the social media can be used for,

- Activities announcement,
- Questionnaire by google form for checking the students' opinion,
- Reminding student for watching VDO, doing assignment, and doing quizzes,
- Inspiration, *etc.*

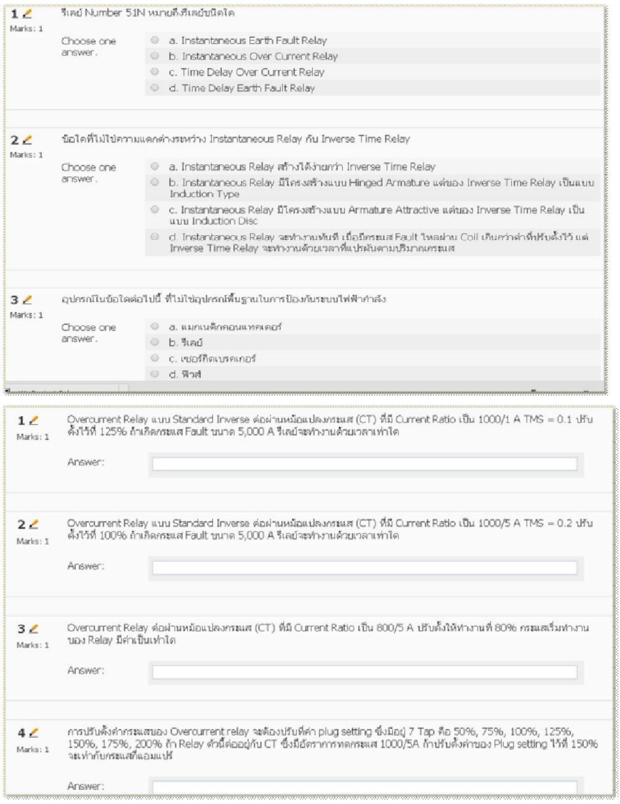


Fig. 4 Sample pages of test bank in e-Learning system

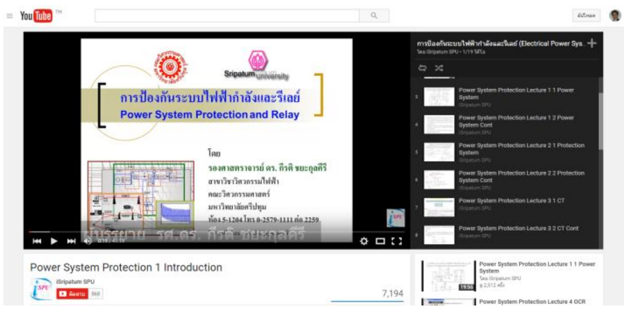


Fig. 5 Youtube used in the class

Fig. 6 Facebook closed group used in the class

With the social media utilizations, the student can access to the class content and information more familiarly with their common on-line social life. In addition, some students are observed to be more relatable to communicate with the class facilitator via social media. The class announcements and encouragements are found to be more effective by these communication channels.

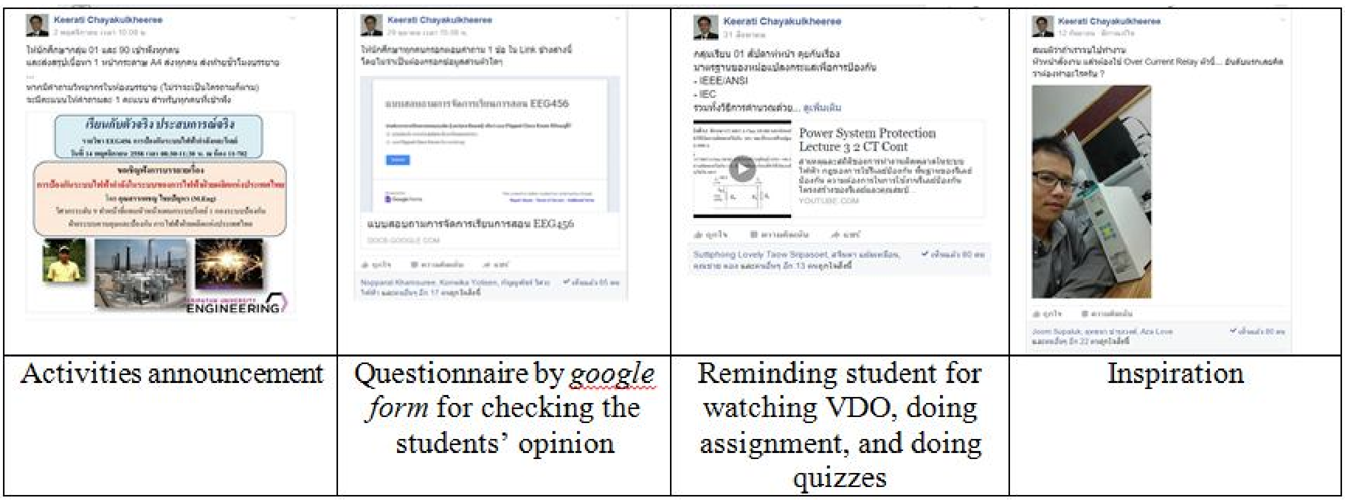


Fig. 7 Example of class activities on Facebook

Fig. 8 *Examples of in class activities under flipped classroom*

C. In Class Activities

The classroom activities are not mainly for lecture. The activities include guiding and encouraging the student to utilize the resources in the e-Learning system and social media, checking and enhancing student understanding, and to share the knowledge gain among students. The teacher is work as class facilitator. The activities are both activities planned ahead before the class and adjustable activities in accordance to the class situation, for example, group solving problem, class knowledge sharing, Ping-Pong Game (http//:gogoopp.com), and group knowledge sharing, as shown in Fig. 8.

4 STUDENT OUTCOME OBSERVATION

The integrated learning class assessment has been done by conducting the student questionnaire and pre-test and post-test process. The questionnaires are collected from 57 students, which is 85.07% of the total class size (67 students). The average score of students' satisfaction on the e-Learning system and social media utilization in the class are 4.42 (/5) and 4.25(/5), respectively. Meanwhile, the average score students' satisfaction on the relation between E-learning and social media is 4.16(/5). The average satisfaction on the overall class facilitation is 4.30(/5), as shown in Fig. 9.

In addition, the pre-test and post-test processes of two topics in the course content, which are "Distance Relay Protection" and "Pilot Protection", indicated that the students increase their examination score from 8.24/20 (approximately 41%) to 16.69/20 (approximately 81%) and from 7.86/20 (approximately 39%) to 16.80/20 (approximately 84%), for the topics "Distance Relay Protection" and "Pilot Protection", respectively. The pre-test and post-test scores are illustrated in Table I and Fig. 10.

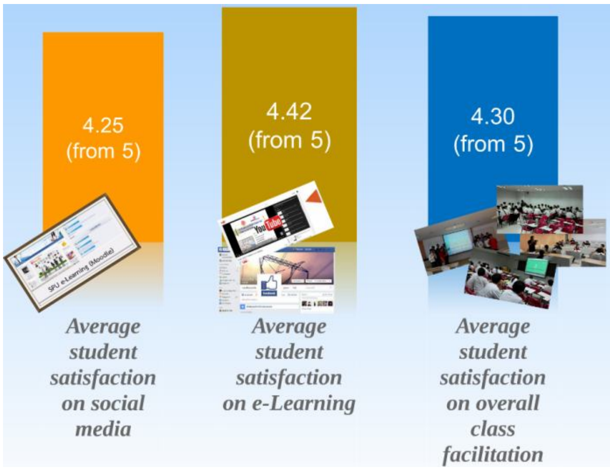


Fig. 9 *Students' satisfaction results*

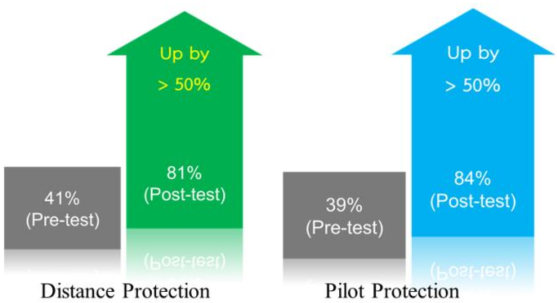


Fig. 10 *Pre-test and post-test results*

5 CONCLUSION

In this paper, an experience on the integrated flipped model, using e-Learning system and social media, is investigated. The advantage features of e-Learning and social media had been adopted. Meanwhile, the classroom is used for encouraging the student to utilize the online resources, checking and enhancing student understanding, and sharing the knowledge gain among students, rather than conventional lecture. The students' satisfaction is very good to the integrated integrated e-Learning and social media flipped classroom. The method also resulted in the high students' learning outcome, observed by pre-tests and post-tests scores.

Table I *Pre-Test and Post-Test Scores for Students Outcome Observation*

Item	Distance Protection			Pilot Protection		
	Pre test (20)	Post test (20)	Incremental Score	Pre test (20)	Post test (20)	Incremental Score
Average Scores	8.24	16.69	8.45	7.86	16.80	8.94
S.D.	2.64	2.77		2.55	1.92	
Minimum	4	7	3	1	11	10
Maximum	14	19	5	13	19	6
Incremental Score on Average			8.45			8.94

6 ACKNOWLEDGMENT

The author would like to pass his deeply thankful to Dr. Vorasuang Duangchinda, Office of Online Education, and Dr. Sirinthorn Sinjindawong, Teaching and Learning Center, Sripatum University, for the valuable supports and suggestions in both teaching techniques and technologies.

REFERENCES

[1] Richard Stanley and Terri Lynch-Caris, "An Innovative Method to Apply the Flipped Learning Approach in Engineering Courses via Web Based Tool," Proceeding of the 2014 ASEE Gulf-Southwest Conference, USA, 2014.

[2] Evan C. Lemley, Baha Jassemnejad, Eric Judd, Brock Philip Ring, Andrew Wayne Henderson, and Grant M. Armstrong, "Implementing a Flipped Classroom in Thermodynamics," Proceeding of the 120th ASEE Annual Conference & Exposition, USA, 2013.

[3] Steven Chetcuti, Hans Thomas, and Brent Pafford, "Flipping the Engineering Classroom Lessons Learned in the Creation, Production and Implementation," Proceeding of the ASEE-2013 Mid-Atlantic Fall Conference, USA, 2013.

[4] Michelle Vaughan, "Flipping the Learning: An Investigation into the use of the Flipped Classroom Model in an Introductory Teaching Course," Educational Research and Perspectives, Vol.41, 2014, 25-41, 2014.

[5] Barbara Kerr, "The Flipped Classroom in Engineering Education," Proceeding of the 2015 International Conference on Interactive Collaborative Learning (ICL), Italy, 2015.

[6] Fatma T. Arslan, "Improved Flipped Classroom Teaching for Electromagnetic Engineering Course," Proceeding of the 2015 ASEE Gulf, Southwest Annual Conference. USA, 2015.

[7] Jacob Lowell Bishop and Matthew A. Verleger, "The Flipped Classroom: A Survey of the Research," Proceeding of the 120th ASEE Annual Conference & Exposition, USA, 2013.

Associate Professor Dr. Keerati Chayakulkheeree received the B.Eng in EE from King's Mongkut Institute of Technology Ladkrabang, Thailand, in 1995. He received M.Eng and D.Eng. degrees in Electric Power System Management from Asian Institute of Technology in 1999 and 2004, respectively. He is currently a Program Director of Graduate Program in Energy and Environmental Management, School of Engineering, Sripatum University, Thailand. His research interests are in power system analysis, optimization and AI applications to power systems, power system restructuring and deregulation, and teaching and learning activities.

IEET Editorial Office

EEAAT - Electrical Engineering Academic Association (Thailand)
Room 409, F-Building
140 Cheum-Sampan Rd.
Nong Chok, Bangkok, Thailand 10530
Tel: +662-988-3655 ext 2216 Fax: +662-988-4026

www.journal.eeaat.or.th