CHAPTER 2

Review of Related Literature

Current electrical power transmission systems

The electrical transmission systems carry the power from the power plants to the distribution that is divided into three zones: generation, transmission and distribution. Transmission system consists of transformers, transmission lines, substations and distribution lines. Electricity flows from power plants, through transformers and transmission lines, to substations, distribution lines, and then finally to the households/consumers. This concept has been termed as “electrical power grid". Figure 2.1 shows the diagram of the electric transmission system.

![Diagram of the electrical transmission system](image)

**Figure 2.1 Diagram of the electrical transmission system**

**Source:** (Southern California Edison Company, 2008)
Normally, the power plants generate three-phase alternating current (AC) and send the AC power to three wire transmission line, one for each phase. The electric grid mainly consists of three separate infrastructure classes: the high voltage transmission line (≥ 500,000 volts), medium voltage transmission line (230, 115, 33, 22 kV) and low voltage distribution system (380, 220 V). The lower voltage distribution system draws electricity from the medium transmission lines and distributes to individual households/consumers.

In the substations, transformers are used to "step down" voltage from the high transmission voltage to medium transmission voltage. Similarly, households use electricity from the distribution system, where transformers are used to "step down" further from medium voltage to low distribution system voltage. As the power plants lie close to the source of fuel (i.e. coal, gas, hydro or nuclear) and very far from the consumers (load) the power generated from power plants must be sent to the loads via high voltage transmission lines. Again transformers are used to "step up" voltage from the generation voltage to a high transmission voltage suitable for long distances. This method minimizes the power losses during the transmission.

**Smart Grid: Future electrical system**

Traditionally, almost every country has centralized bulk generation system. To control the energy balance and other electrical parameters, system operators needed information and data sharing between demand and supply sides. Data communication was very slow because lack of computers and fast data transmission equipments. Present power systems are using computer assisted high speed data transmission and processing systems at the transmission and distribution control centers. The present
power plants can be combined with renewable energy resources such as: wind energy, Photovoltaic system, micro-hydro power for electricity generation to the central grid. However, there are no power demand monitoring in the industrial, commercial and residential sectors. Figure 2.2 shows the electric power transmission system in the past, present and future.

**Figure 2.2 Smart grid concepts in the future**

*Source: (International Energy Agency, 2011)*

In the future, energy generation will rely more on renewables. The renewable energy utilization in the future will be changed from centralized power plant to distributed generation (Ackermann, et al., 2001; Bayod-Rújula, 2009; Pepermans, et al., 2005). The smart grid is an intelligent electric network that uses advanced technology to balance generation sources to meet the electricity demand. It consists of advanced information technologies and real-time communication to improve the power systems’ operations during power exchanges between new technologies of renewable generation, advanced energy storage system and the demand response interactive management (F. Li, et al., 2010; Moslehi & Kumar, 2010).
Smart grids have been presented in terms of their concept, system components and benefits (Blumsack & Fernandez, 2012; Sechilariu, Wang, & Locment, 2013; Wissner, 2011). One of the most important aspects of the smart grids concept is its focus on “smart homes” (Chen, Wei, & Hu, 2013; Di Giorgio & Pimpinella, 2012; Gudi, Wang, & Devabhaktuni, 2012). A smart home is a residence combined with new technology equipment for collecting and sending the data to be utilized by potential applications (J. Li, Da-You, & Bo, 2004; Meyer & Rakotonirainy, 2003; Ricquebourg et al., 2006). Many researchers have developed the concept of smart home to manage the power consumption in their residences. Home energy management system (HEMS) is an answer for power management by using the optimization of power consumption based on power line communication (PLC) (Son & Moon, 2010). It contains methods that coordinate the activities of energy consumption and energy production. The goal of HEMS can be performed the best fit energy production capabilities with consumer need. Electricity consumption can be reduced to support the grid.
Figure 2.3 Technology developments in the part of smart grid concept


From the Figure 2.3, during the last 2 year in the smart home concept, many researches focused on Demand Side Management (DSM) that is a scheduling program to balance the power supply and demand in the residential dwelling equipped with modern technologies (Bahrami, Parniani, & Vafaeimehr, 2012). The availability of data from the grid, such as power consumption, costs of electricity and renewable energy power production, can be used to optimize its efficiency through DSM program. DMS involves the controlling of consumer side loads to operate the system more efficiently by using the proactive approach method (usually by shifting load demands from peak to off-peak periods (Keles et al., 2015)) to control the household’s equipment in order to meet customers’ needs (C W Gellings & Chamberlin, 1987). To promote the DSM
program, appropriate pricing concepts are a key providing the schemes for the end customer by suppliers such as TOU (time-of-use) pricing (Bergaentzlé, Clastres, & Khalfallah, 2014), and real-time pricing with lower rates during off-peak periods (Zehir & Bagriyanik, 2012). Real-time pricing schemes have used the time-based pricing information from the supplier’s rate and thereby, operation times of different residential appliances are determined according to the electricity rates provided. Under the effect of this scheme, customers will change the behavior for using electricity keeping in view the hourly varying energy prices (Mohsenian-Rad, Wong, Jatskevich, Schober, & Leon-Garcia, 2010; Torriti, 2012). TOU schemes are different from real-time pricing concept; here prices are fixed within each TOU pricing period like peak and off-peak demand schedules. Pricing periods are defined according to time of day or day of the week and is easy to implement more than real-time operating aspect.

In the terms of collecting data, advanced metering infrastructure (AMI) is very important in the DSM programs. It is responsible for collecting all the data and information from the loads and RE sources. Smart meters can be used for providing the pricing data to the supplier by customer’s residences (Rashed Mohassel, Fung, Mohammadi, & Raahemifar, 2014). From the survey of AMI technology and its current status it was revealed that AMI cannot report the source/location of renewable energy produced. If the source of electricity is know, this data could be sent to the suppliers. The suppliers can use this data and information for managing the power balance and price management for their customers.
Thailand Power System

Thailand power generation sector is divided into 3 categories: Electricity Generation Authority (EGAT), imports from neighboring countries and domestic private power plants such as: Independent Power Producers (IPP), Small Power Producers (SPP) and Very Small Power Producers (VSPP). EGAT generates the electricity from thermal, combined cycle, hydropower, diesel and renewable energy. All generated power is distributed by the Provincial Electricity Authority (PEA) in the provinces and the Metropolitan Electricity Authority (MEA) in the metropolitan region of Bangkok.

![Diagram of the Thai Power System](image)

**Figure 2.4 Structure of the Thai Power System**

*Source: (Juan Carlos & Larruz, 2013)*

According to the Figure of power generation sector, 41.19% of the electricity in 2016 was generated by EGAT utilities, 13.25% of domestic power producers and 45.56% from neighboring countries ("Electricity Generating Authority of Thailand website "). IPP and SPP supply the power directly to industrial states and may also feed
power into the transmission grid. VSPP are renewable energy resources and small scale power producers connected directly to the distribution grid.

**Photovoltaic System**

The Photovoltaic system is based on a solar cell. In principle the solar cell converts the sunlight into electricity directly (Castaner & Silvestre, 2002). It is basically a p-n junction fabricated in a thin wafer of a layer of semiconductor. In the night time, the I-V output characteristic has an exponential curve similar to the diode (Walker, 2001). The solar cells have many types depending on the materials available for commercial use. Table 2.1 shows the main types of solar cell technologies and their efficiencies (Green, Emery, Hishikawa, Warta, & Dunlop, 2015).

**Table 2.1 Types of solar cell technologies and their efficiencies (Green, et al., 2015)**

<table>
<thead>
<tr>
<th>Classification</th>
<th>Cell Efficiency (%)</th>
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<th>Cell Efficiency (%)</th>
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</thead>
<tbody>
<tr>
<td>Silicon</td>
<td></td>
<td>III-V cells</td>
<td></td>
</tr>
<tr>
<td>Si (crystalline)</td>
<td>25.6±0.5</td>
<td>GaAs (thin film)</td>
<td>28.8±0.9</td>
</tr>
<tr>
<td>Si (multicrystalline)</td>
<td>20.8±0.6</td>
<td>GaAs (multicrystalline)</td>
<td>18.4±0.5</td>
</tr>
<tr>
<td>Si (thin film transfer)</td>
<td>21.2±0.4</td>
<td>InP (crystalline)</td>
<td>22.1±0.7</td>
</tr>
<tr>
<td>Si (thin film minicrystal)</td>
<td>10.5±0.3</td>
<td>Dye sensitised</td>
<td></td>
</tr>
<tr>
<td>Amorphous/nanocrystalline Si</td>
<td></td>
<td>Dye</td>
<td>11.9±0.4</td>
</tr>
<tr>
<td>Si (amorphous)</td>
<td>10.2±0.3</td>
<td>Dye minicrystal</td>
<td>10.0±0.4</td>
</tr>
<tr>
<td>Thin film chalcogenide</td>
<td>Organic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----------------------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td>Si (nanocrystalline)</td>
<td>11.4±0.3</td>
<td>Organic thin film 11.0±0.3</td>
<td></td>
</tr>
<tr>
<td>CIGS (cell)</td>
<td>20.5±0.6</td>
<td>Organic submodule 8.8±0.3</td>
<td></td>
</tr>
<tr>
<td>CIGS (minimodule)</td>
<td>18.7±0.6</td>
<td>Multijunction devices</td>
<td></td>
</tr>
<tr>
<td>CdTe (cell)</td>
<td>21.0±0.4</td>
<td>InGa/GaAs/InGaAs 37.9±1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>a-Si/nc-Si/nc-Si (thin film) 13.4±0.4</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>a-Si/nc-Si (thin film cell) 12.7±0.4</td>
<td></td>
</tr>
</tbody>
</table>

During darkness, the solar cell is not an active device; it works as a diode. It produces neither a current nor a voltage. However, if it is connected to an external supply, it generates a current $I_D$, called diode (D) current or dark current. The diode determines the I-V characteristics of the cell.

\[
I_{pv} = I_L - I_0 \left( \exp \left( \frac{q(V + I_{pv} R_s)}{kT_c A} \right) - 1 \right) - \frac{V + I_{pv} R_s}{R_{sh}}
\]  

(2.1)

Where

- $I_L$ = Light-generated current or photocurrent
- $I_0$ = Cell saturation of dark current
- $q$ = $(1.6 \times 10^{-19} \text{ C})$ is an electron charge
- $k$ = $(1.38 \times 10^{-23} \text{ J/K})$ is Boltzmann’s constant
- $T_c$ = Cell’s working temperature
- $A$ = Ideal factor
- $R_{sh}$ = Shunt resistance
\[ R_s = \text{Series resistance} \]

At the day time and exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create the electron-hole. The photocurrent mainly depends on the solar insolation and cell’s working temperature (Tsai, Tu, & Su, 2008), which is described as

\[ I_L = [I_{SC} + K_I(T_C - T_{Ref})] \lambda \]  \hspace{1cm} (2.2)

Where

- \( I_{SC} \) = Cell’s short-circuit current at a 25°C and 1 kW/m²
- \( K_I \) = Cell’s short-circuit current temperature coefficient
- \( T_{Ref} \) = Cell’s reference temperature
- \( \lambda \) = Solar insolation in kW/m²

On the other hand, the cell’s saturation current varies with the cell temperature, which is described as

\[ I_0 = I_{RS} \left( \frac{T_C}{T_{Ref}} \right)^3 \exp[qE_0(1/T_{Ref} - 1/T_C)/kA] \]  \hspace{1cm} (2.3)

Where, \( I_{RS} \) is the cell’s reverse saturation current at a reference temperature and a solar radiation, \( E_0 \) is the bang-gap energy of the semiconductor used in the cell. The ideal factor (A) is dependent on Photovoltaic technology (Chihchiang & Chihming, 1998).
From equation (1), the $R_{sh}$ is inversely related to shunt leakage current to the ground. In general, the Photovoltaic efficiency is insensitive to variation in $R_{sh}$ and the shunt leakage resistance can be assumed to approach infinity without leakage current to ground. The equation can be rewritten to be

$$I_{PV} = I_L - I_0 \left[ \exp \left( \frac{q(V + I_{PV}R_s)}{kT_cA} \right) - 1 \right]$$ (2.4)

For an ideal Photovoltaic cell, there is no series loss and no leakage to ground, i.e., $R_s = 0$ and $R_{sh} = \infty$. The equation (4) can be rewritten to be

$$I_{PV} = I_L - I_0 \left[ \exp \left( \frac{qV}{kT_cA} \right) - 1 \right]$$ (2.5)

Since a typical Photovoltaic cell produces less than 2 W at 0.5 V approximately; the cells must be connected in series-parallel configuration on a module to increase the power. A group of several Photovoltaic modules is called a Photovoltaic array which is electrically connected in series and parallel circuits. The equation for the current and voltage of the array becomes as follows (Chihchung & Chihming, 1998; Green, 1982; Harrington & Dunlop, 1992; Tsai, et al., 2008).
\[ I_{PV} = N_p I_L - N_p I_0 \left[ \exp \left( \frac{qV}{N_x N_p} \left( \frac{I_{PV} R_s}{N_x N_p} \right) \right) \right] - \frac{N_p V}{N_s + I_{RS}} R_{SH} \]  \hspace{1cm} (2.6)

In most commercial Photovoltaic products, Photovoltaic cells are generally connected in series configuration to form a Photovoltaic module in order to obtain adequate working voltage. The power output is desired by arranging the Photovoltaic module in series-parallel structure. The equation of generalized model can be described as

\[ I_{PV} = N_p I_L - N_p I_0 \left[ \exp \left( \frac{qV}{N_x kT_c A} \right) \right] - 1 \]  \hspace{1cm} (2.7)

For an ideal Photovoltaic cell, there is no series loss and no leakage to ground, i.e., \( R_s = 0 \) and \( R_{SH} = \infty \). The equation (7) can be rewritten to be

\[ I_{PV} = N_p I_L - N_p I_0 \left[ \exp \left( \frac{qV}{N_x kT_c A} \right) \right] \] \hspace{1cm} (2.8)

The open-circuit voltage \( V_{OC} \) and short-circuit current \( I_{SC} \) are the parameters for describing the cell electrical performance that is implicit and nonlinear; therefore, it is difficult to arrive at an analytical solution for a set of model parameters at a specific
temperature and irradiance. Normally $I_{PH} \gg I_0$ and ignoring the small diode and ground-leakage current under zero-terminal voltage, the short-circuit current $I_{sc}$ is approximately equal to the photocurrent $I_{PH}$, i.e. $I_L = I_0$

On the other hand, the $V_{oc}$ is obtained by assuming the output current is zero. Given the Photovoltaic open-circuit voltage $V_{oc}$ at the reference temperature and ignoring the shunt-leakage current, the reverse saturation current at reference temperature can be approximately obtained as

$$I_{RS} = \frac{I_{sc}}{\exp\left(\frac{qV_{oc}}{N_s k T_c A}\right) - 1} \quad (2.9)$$

In addition, the maximum power can be expressed as

$$P_{PP} = V_{max} I_{max} = \gamma V_{oc} I_{sc} \quad (2.10)$$

Where, $V_{max}$ and $I_{max}$ are terminal voltage and output current of Photovoltaic module at maximum power point (MPP), and $\gamma$ is the cell fill factor which is a measure of cell quality.

$$I_{mp} = (I_L - I_0) \left[1 - \frac{V_t}{V_t + V_{mp}}\right] \quad (2.11)$$
The maximum voltage could be calculated by following equation

\[
V_{mp} = V_{OC} - V_i \ln \left[ \left( \frac{V_{mp}}{V_i} \right) + 1 \right]
\]  

(2.12)

The daily power output of a solar array depends on solar irradiation, solar cell temperature and the operating point of the system. Solar irradiation is the integration of solar radiation over time. Normally, standard condition of solar array are rated at a solar radiation level of 1,000 W/m² and a solar cell temperature of 25°C. The solar cell temperature is the temperature of the surface of the Photovoltaic array. In the night time, solar cell temperature is equal to the ambient temperature, but in full sun the cell temperature can increase the ambient temperature by 30°C or more. The output power from the solar array depends on solar cell temperature significantly.

\[
T_c = \frac{T_n + (T_{c,NOCT} - T_{a,NOCT})(\frac{G_T}{G_{T,NOCT}})[1 - \eta_{mp,STC}(1 - \alpha_p T_{c,STC})]}{1 + (T_{c,NOCT} - T_{a,NOCT})(\frac{G_T}{G_{T,NOCT}})[\frac{\alpha_p}{T_c}]}
\]

(2.13)

Where

\begin{align*}
T_c & = \text{Photovoltaic cell temperature (°C)} \\
T_n & = \text{Ambient temperature (°C)} \\
G_T & = \text{Solar radiation striking the Photovoltaic array (kW/m²)} \\
T_{c,NOCT} & = \text{Nominal operating cell temperature} \\
T_{a,NOCT} & = \text{Ambient operating cell temperature}
\end{align*}
\[ G_{T, NOCT} = \text{Solar radiation at which the NOCT is defined (0.8 kW/m}^2) \]

The daily energy output of a solar array can be calculated by (Shen, Tan, See, & Ong, 2005)

\[ P_{PV} = Y_{PV} f_{PV} \left( \frac{G_T}{G_{T,STC}} \right) \left[ 1 + \alpha_P (T_C - T_{C,STC}) \right] \quad (2.14) \]

Where

- \( P_{PV} \) = output of a solar array
- \( Y_{PV} \) = rated capacity of the Photovoltaic array, meaning its power output under standard test conditions (kW)
- \( G_T \) = solar radiation incident on the Photovoltaic array in the current time step (kW/m²)
- \( G_{T,STC} \) = incident radiation at standard test conditions (1,000 W/m²)
- \( \alpha_P \) = temperature coefficient of power (% per °C)
- \( T_C \) = Photovoltaic cell temperature in the current time step (°C)
- \( T_{C,STC} \) = Photovoltaic cell temperature under standard test conditions (25 °C)

Under the standard, Photovoltaic array converts sunlight into electricity at its MPP. The efficiency to calculate any kind of Photovoltaic cell temperature is

\[ \eta_{WP,STC} = \frac{Y_{PV}}{A_{PV} G_{T,STC}} \quad (2.15) \]
Where

\[
\eta_{mp,STC} = \text{efficiency of Photovoltaic under standard conditions}
\]

\[
Y_{pr} = \text{rated capacity of the Photovoltaic array, meaning its power output under standard test conditions (kW)}
\]

\[
A_{pr} = \text{surface area of the Photovoltaic module (m}^2\text{)}
\]

\[
G_{r,STC} = \text{radiation at standard test conditions (1,000 W/m}^2\text{)}
\]

**Architecture and power flow of the system**

For this study, the office buildings having Photovoltaic systems on their rooftop have been used. The power flow of a building depends on the amount of power consumption and power production that is divided into 2 ways. When the electricity from the Photovoltaic is more than the power consumption, the power flow of the building is supplying into production, the power flow is needed from the outside for balancing the building. The power flow of the building was calculated based on the equation below.

![Diagram](image)

*Figure 2.5 Architecture of the RE system in the building*
Figure 2.6 Architecture of the power flow in the communities

In Figure 2.5, $P_{\text{hdlg}}$, $P_{\text{land}}$, & $P_{\text{pv}}$ represent the power flow at an interconnection that is outside of the building, power consumption & Photovoltaic output power from Photovoltaic array respectively, where:

$$P_{\text{land}} + P_{\text{pv}} = P_{\text{hdlg}}$$  \hspace{1cm} (2.16)

The power balancing can maintain the equilibrium state by reducing the interconnection point power flow fluctuation to satisfy the above equation: (Tanaka et al., 2012)
Objective function:

$$
\min F = \sum_{i \in T} (B_i - P_{grid})^2
$$

(2.17)

Constraints:

$$
P_{grid\ min} < P_{grid} < P_{grid\ max}
$$

(2.18)

Where

- $T = \text{All time section}$
- $B_i = \text{Interconnection point power flow reference}$
- $P_{grid} = \text{Interconnection point power flow from power building to grid}$
- $P_{grid\ min} = \text{Interconnection point power flow bandwidth minimum value}$
- $P_{grid\ max} = \text{Interconnection point power flow bandwidth maximum value}$

In Figure 2.6, $P_{overall}$, $P_{comm}$, $P_{bldg}$ represent the interconnection point power flow, power flow in community, power flow in a building, where:

$$
P_{comm} = \sum_{i=1}^{n} P_{bldg}^{(i)}
$$

(2.19)

$$
P_{overall} = \sum_{i=1}^{m} P_{bldg}^{(i)}
$$

(2.20)

Where

- $n = \text{a number of building in the community}$
- $m = \text{a number of community}$
From the power flow in the building, the real time energy flow of the building depends on the summation of the power consumption and power production that is called net metering. Net metering can show the direction of power flow in each building. If net metering shows a minus value that means building needs power from the outside to maintain power balance. In this case study the power supply to the building may come from renewable energy (Photovoltaic array from another building), or utilities grid for distribution (PEA) as a result of power flow load balancing algorithm. Net metering in the each building shows power flow direction and amount, using these information, the community's power flow can be calculated by summation of these values. The overall power flow is then the summation of the net metering of the communities.

**Array digital record**

The array is the most widely used in the data structure. It consists of components which are all of the same type, called its base type; it is a homogeneous and a random-access structure because all components can be selected at random and are equally quickly accessible. The name of the entire structure is augmented by the index selecting the component. This index is to be an integer between 0 and n-1, where n is the number of elements, the size, of the array (Wirth, 1985).
TYPE T = ARRAY n OF T0

For example,

\[
\begin{align*}
\text{TYPE Row} & = \text{ARRAY 4 OF REAL} \\
\text{TYPE Card} & = \text{ARRAY 80 OF CHAR} \\
\text{TYPE Name} & = \text{ARRAY 32 OF CHAR}
\end{align*}
\]

A particular value of a variable

VAR x: Row

With all components the equation \( x_i = 2^{-i} \), may be visualized as shown in below;

\[
\begin{array}{c|c}
X_0 & 1.0 \\
X_1 & 0.5 \\
X_2 & 0.25 \\
X_3 & 0.125 \\
\end{array}
\]

An individual component of an array can be selected by an index. Assume \( X \) is a variable, can denote an array name followed by the respective component’s index i. The array \( X \) and index \( i \) can define in the symbol as \( X_i \) or \( X[i] \).

The common way of operating with arrays is to selectively update single components rather than to construct entirely new structured values. This is expressed by considering an array variable as an array of component variables and by permitting assignments to select components, such as for example \( x[i] := 0.125 \). Although selective updating causes only a single component value to change, from a conceptual point of view, it must regard the entire composite value as having changed too.
The cardinality of a structured type is the product of the cardinality of its components. Since all components of an array type $T$ are of the same base type $T^0$, it will obtain

$$\text{card}(T) = \text{card}(T^0)^n$$  \hspace{1cm} (2.22)

Constituents of array types may themselves be structured. An array variable components are again arrays is called a matrix. For example

$$\text{M: ARRAY 10 OF Row}$$  \hspace{1cm} (2.23)

From example, is an array consisting of ten components (rows), each consisting of four components of type REAL, and is called a $10 \times 4$ matrix with real components. Selectors may be concatenated accordingly, such that $M_{ij}$ and $M[i][j]$ denote the $j$ the component of row $Mi$, which is the $i$ the component of $M$. This is usually abbreviated as $M[i,j]$ and in the same spirit the declaration.

$$\text{M: ARRAY 10 OF ARRAY 4 OF REAL}$$  \hspace{1cm} (2.24)

It can be written more concisely as

$$\text{M: ARRAY 10, 4 OF REAL}$$  \hspace{1cm} (2.25)
If a certain operation has to be performed on all components of an array, then
FOR statement may conveniently be emphasized by using in the array, as shown in the
following examples for computing the sum and for finding the maximal element of an
array declared as

VAR a: ARRAY N OF INTEGER
sum := 0;
FOR i := 0 TO N-1 DO sum := a[i] + sum END
k := 0; max := a[0];
FOR i := 1 TO N-1 DO
  IF max < a[i] THEN k := i; max := a[k] END
END.

In a further example, assume that a fraction \( f \) is represented in its decimal
form with \( k-1 \) digits, i.e., by an array \( d \) such that

\[
f = \sum_{i=0}^{i<k} d_i \cdot 10^i \quad (2.26)
\]

\[
f = d_0 + 10 \cdot d_1 + 100 \cdot d_2 + \ldots + 10^{k-1} \cdot d_{k-1} \quad (2.27)
\]

Now assume that \( f \) is divided by 2. This is done by repeating the familiar
division operation for all \( k-1 \) digits \( d_i \), starting with \( i=1 \). It consists of dividing each
digit by 2, and of retaining a possible remainder \( r \) for the next position:

\[
r := 10 \cdot r + d[i]; \ d[i] := r \ \text{DIV} \ 2; \ r := r \ \text{MOD} \ 2 \quad (2.28)
\]
**Software Development Life Cycle**

SDLC is a process of software development. It consists of 6 stages: planning, defining, designing, building, testing and deployment. The objective of the life cycle defines a methodology for improving the quality of the software as shown in Figure 2.7 below.

![SDLC Diagram]

**Figure 2.7 Six steps for SDLC concept**

*Source:* (“Software Development Life Cycle (SDLC)”)

**Stage 1: Planning:** Planning is a part of requirement analysis and is most important and fundamental stage in the SDLC. It is performed by some person who is responsible for giving the information of the project. This information is used to plan the basic project and to conduct product feasibility study in the economic, operational, scope of areas and risk analysis.

**Stage 2: Defining:** next step of the requirement analysis, it is to clearly define and document and get them approved by the customer. It is called “SRS: Software Requirement Specification” document, which consists of all detail of requirement to be designed and developed during the project life cycle.
Stage 3: **Designing:** Product architects in developing software is in SRS document. Usually, more than one design approach for the product architecture is proposed and having in a “DSS: Design Document Specification”. This document is approved by all customers and based on minimums risk assessment.

Stage 4: **Building:** This stage is developing the product by coding the programming language such as C, C++, Pascal, Java or PHP. Developers have to follow the coding guidelines defined by their organization and programming tools like compilers, interpreters, and debuggers etc. which are used to generate the code.

Stage 5: **Testing:** This stage is usually a subset of all stages, but it is mostly involved in the testing only stage of the product, where product defects are reported, tracked, fixed and retested, until the product reaches the quality standard defined in the SRS documents.

Stage 6: **Deployment:** Once the product is tested and ready to use in the market, the product is released in the market, its maintenance is done for the existing customer base.

**SDLC Models**

SDLC model is a various software development life cycle. The most popular SDLC models are followed in the industry such as: waterfall model, iterative model, spiral model, V-model and big bang model. In this research, we will use the waterfall model for the guideline to develop the software.
Waterfall Model design, the first of SDLC model is a waterfall concept model that is used widely in Software Engineering to build the software project. The waterfall model is divided into 6 steps, namely, requirement analysis, system design, implementation, testing, deployment, and maintenance ("Software Development Life Cycle (SDLC),").

**Figure 2.8 Diagrammatic representation of different phases of waterfall model**

*Source: Software Development Life Cycle (SDLC)*

The sequential phases in Waterfall model are:

- **Requirement analysis:** It is to develop the requirement specification document that is created from the all the possible requirements of the customer.
- **System Design**: It is to prepare and define overall system architecture by improving the requirement specification document. System design helps in specifying hardware and system requirements.

- **Implementation**: Firstly, the system is developed in small programs called units. Each unit is to be developed and tested for its functionality. All of these functions are referred as Unit testing.

- **Integration and Testing**: The units from the implementation phase needed to integrate into a system after testing of each unit for any faults and failures.

- **Deployment of the system**: After the testing is done, the product is deployed into the market.

- **Maintenance**: After deployment of the product into the market, there may be some problems which may come up from the client environment or the customer. To fix these problems, the new patches are released to implement changes in the customer environment.